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LA THÈSE A ÉTÉ
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AN ETHER SEARCH

by

MARTIN EDWARD KING, M.Sc.

A thesis submitted to the Faculty of
Graduate Studies in partial fulfillment
of the requirements for the Degree of

Doctor of Philosophy.

Department of Physics

Carleton University

Ottawa, Ontario

September 1977

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Martin Edward King 1977

The undersigned recommend to the Faculty of Graduate Studies acceptance of the thesis "An Ether Search" submitted by Martin Edward King, M.Sc., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

A first order ether search experiment is described. The anisotropy of space is determined by measuring changes in the beat period ΔP of two 5 MHz oscillators at opposite ends of a rotating arm. Theoretically expected changes based on the assumption of a stationary ether are compared to the experimentally observed ΔP and a value of $\bar{v}/c$ is calculated.

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CHAPTER I

INTRODUCTION

Ever since light was found to have wavelike properties, the search for the ether, or medium through which light was thought to propagate (or equivalently the hypothetical absolute reference frame), has continued until the present day. The ether was thought to be a material which existed in a stationary form everywhere in the universe. It was believed that light travelled through this material at a constant velocity c and that the velocity of light as measured by an observer moving with velocity v with respect to the stationary ether would be $c + v$. The first experiment designed specifically to look for the ether was that conducted by A.A. Michelson (1) in 1881 at Potsdam, Germany. His experiment, as the vast majority of later experiments (Table 1-1), was of the interferometer type. It thus could measure only second order effects ($\beta^2 = (v/c)^2$). In this thesis an experiment is described and results presented of a method which is sensitive to β and thus also gives the sign of v .

It is of some interest to follow the historical developments of the ether search (28). While an instructor in Physics at Annapolis (1875-1879) Michelson performed his first measurements on the velocity of light. His successful results using an improved Foucault rotating-mirror apparatus led to his transfer to the Nautical Almanac Office under Simon Newcomb. Here he carried on his research on the velocity of light and developed an interest in the medium or ether through which light propagated.

OBSERVER	YEAR	PLACE	$ \beta $
Michelson (1)	1881	Potsdam	$.5 \times 10^{-4}$
Michelson and Morley (2)	1887	Cleveland	$.1 \times 10^{-4}$
Morley and Miller (3)	1902-4	Cleveland	$.08 \times 10^{-4}$
Miller (4)	1921	Mt. Wilson	$.19 \times 10^{-4}$
Miller (5)	1923-4	Cleveland	$.12 \times 10^{-4}$
Miller (6)	1924	Cleveland	$.08 \times 10^{-4}$
Tomaschek (7)	1924	Heidelberg	$.19 \times 10^{-4}$
Miller (8)	1925-6	Mt. Wilson	$.2 \times 10^{-4}$
Kennedy (9)	1926	Pasadena Mt. Wilson	$.1 \times 10^{-4}$
Illingworth (10)	1927	Pasadena	$.05 \times 10^{-4}$
Piccard and Stahel (11)	1927	Mt. Rigi	$.18 \times 10^{-4}$
Michelson, et al. (12)	1929	Mt. Wilson	$.075 \times 10^{-4}$
Joos (13)	1930	Jena	$.037 \times 10^{-4}$

Table 1-1: List of second order ether experiments performed up to 1930. The last column lists the maximum possible value of $|\beta|$ that the respective experiments detected. The absolute value of β is given as the second order experiments can not determine the sign of β .

This interest was aroused initially by a letter written by Maxwell inquiring about the accuracy of the existing observations of the eclipses of Jupiter's satellites with the intention of using such data to determine the absolute motion of the earth through the ether. Maxwell also stated that at present (1879) no terrestrial method of measuring the speed of light existed which could determine the earth's motion through the ether. This challenge led Michelson to study interferometry methods and this became his chief research while in Europe.

He carried out most of his research at von Helmholtz's laboratories in Berlin. Here he studied Jamin's interferometer and saw how to develop his own. His first instrument was built by a firm in Berlin using optical flats made by a firm in Paris. The funds for the first stationary ether search came from a grant furnished by Alexander Graham Bell. The experiment was initially set up in Berlin but was later moved to Potsdam because of excessive vibrations due to traffic in Berlin.

The Michelson interferometer is based on division of amplitude. Light from a source is split by a beam splitter and the two beams allowed to travel different path lengths before they are recombined at the splitter. An observer looking at parallel light sees circular fringes apparently emanating from two virtual sources separated by a distance $2d$. Maxima occur at $2d \cos\theta = m\lambda$ where λ is the wavelength of the light. In the actual experiment (1881) two arms each 120 cm. long were mounted at right angles to one another. Light from a source

was made parallel by a lens and this parallel beam was split at the junction of the two arms by a beam splitter. Each beam was returned to the beam splitter and telescope by plane mirrors at the ends of the two arms. In his initial analysis Michelson used an incorrect formula. As worked out in the stationary ether frame the time for a wave front to travel from the splitter to the mirror and back, moving parallel with the earth's orbital velocity vector is

$$\frac{2\ell}{c} \frac{1}{1-\beta^2} \quad \text{where} \quad \begin{array}{l} c \text{ velocity of light} \\ \ell \text{ path length of one arm} \\ v \text{ velocity of earth (ether)} \\ \beta = v/c \end{array}$$

while for the beam moving perpendicular to the velocity, striking a mirror and returning the time is $\frac{2\ell}{c}$. This latter time interval is incorrect as was later pointed out by Lorentz. The correct form was $\frac{2\ell}{c} \frac{1}{\sqrt{1-\beta^2}}$. Nevertheless Michelson determined that he should be able to see a shift of $\Delta\lambda/\lambda = .04$ in the interference rings. The correction by Lorentz cut this to .02. His uncertainties were so large though that most theorists ignored his null result.

At this time H.A. Lorentz was working on his theory of the electron. The only aspect of this theory related to the present topic is that his electrons and positively charged atoms supposedly existed in the ether in which an electromagnetic field existed obeying Maxwell's equations. His electron theory was highly successful in describing such properties as colour

dispersion and the magnetic rotation of the plane of polarization. However, the further development and success of the theory led Lorentz to declare that the ether was at absolute rest everywhere and in all matter, thus denying the possibility of partial drag. This theory was even able to explain the results of Fresnel's convection experiments, in which light in an interferometer was passed through a moving fluid. Michelson and Morley in their first collaboration repeated Fresnel's experiment with far greater accuracy, but they obtained the same result.

Michelson and Morley (2) then in 1887 repeated Michelson's experiment with far greater accuracy using a larger interferometer with arms 1100cm long, mounted on a granite block floating in a pool of mercury. This experiment also gave a null result and definitely showed that "if there was an ether" that it was pulled along by the earth. This result led Lorentz in 1895 to modify his theory of the electron by introducing the contraction hypothesis which stated that a measured length in the frame moving in the direction of motion contracted by an amount $\sqrt{1-\beta^2}$ while in the stationary ether frame the length remained unchanged. The contraction principal had been first suggested by Fitzgerald about six years earlier. In 1899, Lorentz derived his now famous transformations between frames of reference.

In Appendix 1 Michelson and Morley's results of 1887 are presented. My analysis of the data is given along with the expected results. From their data Michelson and Morley

concluded that the results are consistent with the statement that the ether was being dragged by the earth. This conclusion contradicted the results of convection experiments which indicated that there must be at most only a partial drag. This led Lorentz to enunciate his contraction hypothesis. Following Einstein's publication of his Theory of Relativity the search carried on. Although now the motivation was to distinguish between Lorentz contraction theory and Relativity theory. Table 1 presents a list of experiments which were carried out between 1881 and 1930. The experiments from 1926 to 1930 were performed because of the positive results found by D.C. Miller in 1925. His investigations, using a large Michelson interferometer, resulted from pressure from Morley and his belief that the 1887 experiment had shown a possible effect.

In Appendix 2 one set of Miller's (8) data is given along with the expected results. Analysis of the data shows a definite effect, but as discussed in the appendix the effect is very unlikely to have been caused by an ether velocity. However, his results lead to several other experiments, none of which verified his observations. In spite of these, Miller's experiments could not be ignored, because of his stature in the scientific community and the certainty of the quality of the experiments. Miller's ~~data~~^{were} ~~was~~ reanalyzed in 1955 by R.S. Shankland et al. (14). They concluded that the prime cause for any observed effect was due to temperature variations, although there were a few sets of data they could not explain.

In 1955, L. Essen (15) published the results of his ether search experiment. He used a resonant cavity to control the frequency of an oscillator. As the cavity was rotated through an angle θ , the effect of an ether velocity should have been to have caused the controlled oscillator frequency to have fractional shifts of $\frac{1}{2} (v/c)^2 \sin\theta$. The obtained periodic pattern was thought to be due to magnetostrictive effects on the cavity. It was concluded that any effect due to the ether, should it exist, had to be less than .1% of the expected value. That is v , the ether velocity, was less than 30 m/s, as compared to the expected 30 km/s.

J.P. Cedarholm et al. (16) performed the first experiment (1958) which directly measured $\beta = v/c$. They measured changes in the beat frequency between two anti-parallel ammonia masers as the masers were rotated. The fractional change in frequency due to the classical Doppler effect is uv/c^2 where u is the velocity of the ammonia molecules in the maser. Assuming a stationary ether, the expected shift was 20 Hz but no variation greater than $\pm 1/50$ Hz was observed other than that due to vibrations and magnetostrictive effects which caused shifts of up to 1 Hz.

T.S. Jaseja, C.H. Townes et al. (17) performed a similar experiment in 1963. In this experiment two H₂Ne masers were mounted at right angles to each other and the beat frequency between the two was observed as they were

rotated about a vertical axis. In this case the expected frequency change was $(v/c)^2$, making this a second order experiment. They concluded that β was less than 10^{-7} .

The null results of all of the previous experiments can be explained by assuming the Lorentz-Fitzgerald contraction for any length parallel to the motion through the ether and also the appropriate time dilation, while still assuming the existence of the stationary ether. Hence, it now becomes important to design an experiment which can distinguish between contraction theory and relativity. The first attempt at this was an experiment designed by M. Ruderfer (18) which made use of the Mössbauer effect (see Figure 1-1). The actual experiment was carried out by D.C. Champeney et al. (19) in 1963. The Mössbauer effect results from recoil-less resonant fluorescence for γ -rays which occurs when the nucleus, which emits a photon, shares its recoil momentum with the crystal. The γ -ray may then be absorbed by an identical atom in a crystal, in what is called the absorber, which in turn re-emits a characteristic γ -ray. If the original photon is emitted and an ether is postulated then there is a frequency shift given by

$$\Delta\nu/\nu = \bar{v} (\bar{u}_a - \bar{u}_s)/c^2$$

where $\bar{v}$ is the velocity of the ether with respect to the laboratory, $\bar{u}_a$ and $\bar{u}_s$ are the velocities of the absorber and source relative to the laboratory, $\Delta\nu/\nu$ is the relative

Fig. 1-1; Arrangement of apparatus for
Ether search using Mössbauer
Radiation.

increase in frequency received by the absorber and c is the velocity of light. This experiment concluded that $\bar{v} = 1.6 \pm 2.8$ m/s. However, it had been shown by M. Ruderfer (20) in 1961 that the experiment was not capable of distinguishing between contraction theory and relativity.

This was left to the present experiment and a similar one performed in 1972 by R. Cialdea (21). In Cialdea's experiment (Figure 1-2) two HeNe lasers were mounted on a rotatable table. The outputs of the lasers were mixed together. If a stable beat pattern was observed the table was rotated. The change in transit time along the path L should have caused the beat pattern to shift, change shape or disappear. Since no change in the beat pattern was observed as the table was rotated Cialdea concluded that the ether velocity was less than .9 m/s, this being his estimated resolution. However, there are several problems with this experiment. The first is associated with the coherence time of the laser which is usually less than fractions of seconds long. This is especially true when the laser is vibrated as is in the case when the table is rotated. To obtain coherence between two lasers for periods of 5 to 10 seconds is very difficult. Second, should such a beat pattern be obtained, the pattern should shift or disappear as the table is rotated due to the magnetostrictive effects on the lasers. Third, the acceleration on the lasers should produce a variable pattern, due to changing stresses on the apparatus. This is one reason why other experiments have a constantly rotating . Even at best the smallest vibrations in the

Fig.1-2: Arrangement for laser ether search experiment.

S_1 is a partially reflecting mirror

S_2 is a totally reflecting mirror

Lasers and mirrors are mounted on a rotatable table.

rotating mechanism create background patterns which distort the results.

The experiment described in this thesis should be capable of distinguishing between Lorentz-Fitzgerald contraction theory and relativity. This is accomplished by applying the length contraction and observing that it is of second order and thus does not extinguish the expected results, as described in the next chapter. One possible weakness with the experiment is that it was performed with signals in a transmission line and not with visible light in an unobstructed vacuum. The source of this possible weakness is shared with all other experiments except that of Champeney. The common fault is that the electromagnetic waves in these experiments travelled through or were reflected from intervening material such as air, glass lens or transmission lines. As a consequence of the extinction theorem, in the theory of the dispersion of light, the velocity of light may be characteristic of the intervening material rather than depend on an ether velocity (22).

The extinction theorem (23) states that an electromagnetic wave incident on a surface is extinguished by the dipoles on the boundary of the medium. The extinction takes place in a distance $\ell \approx \frac{k}{n\sigma}$, where k is the square of the number of electrons in a length $\lambda/2\pi$, where λ is the wavelength of the incident radiation, n is the number of scattering electrons per unit volume and σ is the scattering cross section. ℓ is about 10^{-4} cm for solid matter and about 1 mm for air at STP. The incident wave is extinguished in this distance ℓ

and replaced by a new scattered wave whose source is the dipoles, only if the incident frequency is low enough (several electron volts) that the dipoles can follow the incident frequency. It is for this reason that Champeney's experiment may not be affected by small amounts of intervening material. It is only speculation that this extinction may have any effect on these experiments (22, 24). This possibility led to a re-examination of past experiments and a series of new ones to determine the validity of the extinction theorem (25,26). No such proof was forthcoming but lingering doubt remains.

CHAPTER, II

THEORY OF MEASUREMENT

This section discusses two methods for determining a possible value of the ether velocity assuming the existence of a stationary ether. Both methods are of the first order type; that is they measure $\beta = v/c$ directly unlike the 2nd order type (interferometers) which directly measure β^2 .

In the first method (called the TAC method because it uses a time to amplitude converter) two identical but totally independent oscillators are located a distance L apart. Both oscillators transmit pulses alternately to each other. At both locations (see Figure 2-1) labelled A and B the time interval between the emission of a signal from oscillator A at A and the arrival at A of a signal from B is measured and similarly at B the interval between the emission of a signal from oscillator B and the arrival at B of a signal from A is measured. The intervals obviously depend upon the transit time along the path between the two oscillators. The time interval as measured at A is

$$t_A = t_{AO'} + t_{BO} + \frac{L}{c+v} + \phi - t_{AA}. \quad (2-1)$$

Similarly at B, the interval is

$$t_B = t_{AO} + t_{BO'} + \frac{L}{c-v} + (T-\phi) - t_{BA}. \quad (2-2)$$

The difference between these intervals is

$$\begin{aligned}
 \Delta t_{A-B} &= \frac{L}{c+v} - \frac{L}{c-v} + \phi - (-\phi) + (t_{A0'} - t_{AA}) + (t_{B0} - t_{A0}) \\
 &= (t_{B0'} - t_{BA}) - T \\
 &= \frac{-2BL}{c} + 2\phi - T + (t_{A0'} - t_{B0'}) + (t_{BA} - t_{AA}) + (t_{B0} - t_{A0})
 \end{aligned}
 \tag{2-3}$$

ignoring second order terms in β .

Equation (2-3) depends on both oscillators having the same frequency. It can be seen that as one drifts with respect to the other that the effect is doubled, i.e. ϕ changes. If the time interval at end A is being measured then at end B it is possible to measure

$$\Delta t_B = t_{B0} + t_{B0'} - t_{BA}$$

and similarly in the opposite case

$$\Delta t_A = t_{A0} + t_{A0'} - t_{AA}$$

These two measurements may also be combined with equation 2-3 to give

$$\Delta t_{A-B} = \Delta t = \frac{-2BL}{c} + 2\phi - T + (t_{A0} - t_{B0}).$$

This equation is not particularly useful, however knowledge of Δt_A and Δt_B is since they measure any changes in gain of the TACS.

The velocity of the signals travelling along the path length depends upon the component of the ether velocity in this direction. If the arm remains fixed in the laboratory then the velocity depends upon a function with a 24 hour period. If the path length rotates in the laboratory on an arm, on what is called the merry-go-around (MGR), then the velocity also depends upon a function with the period of the

DEFINITION OF SYMBOLS

L	path length between oscillators
c	velocity of light
v	component velocity of ether along the path length
ϕ	phase difference between oscillators
T	period of oscillators
$t_{AO'}$	delay time of end A between junction of transmission line to B and Time to Amplitude Converter (TAC)
$t_{BO'}$	as above but for end B
t_{AA}	end A delay time between output of oscillator at A and input to start of TAC
t_{BA}	as above but for end B
t_{AO}	is the time delay from Oscillator A to junction of transmission line
t_{BO}	is the time delay from Oscillator B to junction of transmission line

Δt_A and Δt_B are measured drifts in the respective TAC's.

MGR (~ 1.7 seconds). Data may be collected at various positions in the laboratory and at various times throughout the day, over a period of many days or months.

The second method (called the Beat Method) makes use of the fact that it is practically impossible to have both oscillators with the same frequency. One oscillator frequency is offset from the other. This gives a beat period

$$P_b = \frac{P_A P_B}{P_A - P_B} = \frac{P_A P_B}{\Delta P}$$

where P_A and P_B are the periods of oscillators A and B respectively. Now consider what happens to P_b if an ether velocity v exists and the path length rotates so that during a beat period the transit time along the path varies with the propagation velocity $V = c + v$.

The pulse at B travels to A in a time L/v_0 where v_0 is the transit velocity at time 0, the start of the beat period. The time of arrival at A of the second oscillator pulse from B is $P_B + L/v_1$ where v_1 is the transit velocity during this time interval. v_1 is of course different from v_0 since during P_B the path length's orientation in space has changed. Thus the period of B measured at A is $P_B + L \left(\frac{1}{v_1} - \frac{1}{v_0} \right)$. This process continues until the end of the beat period, as shown below. The sum of all the periods measured at A is then the beat period.

<u>time at end B</u>	<u>time of arrival of B at A</u>	<u>Period of Oscillator B's pulses measured at A.</u>
0	L/v_0	
P_B	$P_B + L/v_1$	$P_B + L/v_1 - L/v_0$
$2P_B$	$2P_B + L/v_2$	$P_B + L(\frac{1}{v_2} - \frac{1}{v_1})$
nP_B	$nP_B + L/v_n$	$P_B + L(\frac{1}{v_n} - \frac{1}{v_{n-1}})$

BEAT PERIOD $P_b = \text{sum of above}$

$$= nP_B + L(\frac{1}{v_n} - \frac{1}{v_0})$$

$$= nP_B + \frac{L}{c} (\frac{1}{1+\beta_f} - \frac{1}{1+\beta_i}) \quad (2-4)$$

$$= nP_B + t_f - t_i$$

where $v_i = c + v_{\text{ether}}$, and t_i and t_f are the initial and final transit times along L . The β_i 's are of course the component values of V , the ether velocity divided by c along the path length which depend upon the path length's orientation in space.

The beat period also equals mP_A where m and n are integers.

The smallest value of n is $m+1$ and therefore

$$mP_A = (m+1) P_B + t_f - t_i$$

But

$$P_B = P_A - \Delta p. \text{ Therefore } m = \frac{P_B + t_f - t_i}{\Delta p}$$

m is counted for each beat period and is the measured quantity.

$$\Delta m = \frac{t_f - t_i}{\Delta p} \text{ and is the quantity which depends on the}$$

ether velocity. As before, data may be collected at various positions in the laboratory and at various times.

The transit time of a signal along the MGR arm is developed, for use in both methods one and two, based on the assumption that there exists a stationary ether. Three models are assumed for the earth's motion through the stationary ether. First, only the simple case of the earth moving about the sun is considered.

The model then becomes more complicated when galactic rotation and motion towards the constellation Perseus is included (27). Finally the intermediate case of motion about the sun and galactic rotation is considered.

In the simple case as shown in Figure 2-2, the transit time t for a signal along the path L at an arbitrary angle θ from the direction of the motion of the earth through the ether is developed from

$$(ct)^2 = (L \sin\theta)^2 + (L \cos\theta + vt)^2 \quad (2-5)$$

Here it is assumed that the signal is travelling at a speed c in the stationary ether. The path length L is broken up into two components, one parallel to the direction of motion of the earth and the other perpendicular to this motion. These components are respectively, $L\cos\theta$ and $L\sin\theta$, Figure 2-3. Since the earth is assumed to be moving through the ether with a velocity v it follows that the parallel component must be modified to become $L\cos\theta + vt$. Equation (2-5) gives the transit time t to be

$$t = \frac{2vL\cos\theta + \sqrt{(2vL\cos\theta)^2 + 4(c^2 - v^2)L^2}}{2(c^2 - v^2)} \quad (2-6)$$

$$= \frac{L}{c} \frac{\beta \cos\theta + \sqrt{(\beta \cos\theta)^2 + (1 - \beta^2)}}{1 - \beta^2}$$

where $\beta = v/c$.

The problem now is to find the components of the path L with respect to the direction of the earth's motion, in this

case, about the sun. This is solved in stages, first examining the geometry of the path length L in the laboratory coordinate system, then on an earth based system and finally on a sun based system.

In the laboratory the path rotates with an angular frequency ω about an axis which is perpendicular to the earth's surface at a latitude $90^\circ - \phi$. In Figure 2-4, the coordinates of the half path length L are shown. The angle of rotation $\theta = \omega t$ is measured from the x axis which is directed due east, in a counter clockwise direction. The components of L are $L_x = L \cos \theta$ and $L_y = L \sin \theta$.

If the axis of rotation of the path length is projected down to meet the axis of rotation of the earth, then the above components can be rewritten in terms of a coordinate system centered on the axis of rotation of the earth. This (primed) system has its y axis parallel to the axis of rotation of the earth and its x axis perpendicular to this axis at 0 hours. This geometry is shown in Figure 2-4. L lies on a plane x - y at an angle θ from $y=0$. This plane lies at an angle ψ to the x' - y' plane. The x' - y' plane rotates about the axis of rotation of the earth every 24 hours.

The components of L in the primed system in terms of the un-primed system are as follows:

$$L_{x'} = L_x = L \cos \theta$$

$$L_{y'} = L_y \cos \psi = L \sin \theta \cos \psi$$

$$L_{z'} = \sqrt{L_y^2 - L_{y'}^2} = L \sin \theta \sin \psi$$

$$L' = \sqrt{L_{y'}^2 + L_{x'}^2} = L \sqrt{\cos^2 \theta + \sin^2 \theta \cos^2 \psi}$$

$$\theta' = \arctan (\tan \theta \cos \psi)$$

$$\psi = \arcsin (\sin \theta \sin \psi) = \text{angle between } L \text{ and } L'.$$

The earth moves in an orbit about the sun, however, its axis is tilted away from the normal to the plane of the orbit. Thus, the primed frame can be considered to be rotating about a fixed point (the sun) on this plane, but riding on a tilted plane as shown in Figure 2-5. The orbit plane defines the double prime frame. The origin of this frame is coincident with the origins of the other two frames. The X'' axis lies in the direction of motion of the earth at the instant of Winter Solstice. The double primed components of the path length are to be used to find the transit time.

In Figure 2-5 the primed frame is defined by the labels OABCDEF. The base of the frame, OABC, rests on the plane defined by A'B'C'D'. This plane lies at an angle $\tau = 23.5^\circ$ to the plane defined by A'B''C''D''. It is in this last plane that the earth is rotating about the sun with an orbital velocity $v = 30$ km/sec. The primed frame OABCDEF rotates about the origin O on the tilted plane once every day and also in addition effectively once a year. The origin O actually rotates about the sun once a year but this effect can be taken into account by appropriately writing the angle $\angle AOA'$.

Keeping θ fixed and the time of day fixed then the

projection of OX' onto the orbit plane rotates about the sun in one year. The angle that the projection of OX' makes with OX'' is t_d and is the measure of the yearly rotation. The projection of this angle onto the tilted plane is given by

$$f(t_d) = \arctan(\tan(t_d)/\cos(\tau)).$$

It also follows that as the primed frame rotates about O once a day that the angle between OX' and OX'' becomes

$$\angle AOA' = H + f(t_d)$$

where H is the measure of daily rotation.

From Figure 2-6 it can be seen that ObB lies on the tilted plane and Oed lies on the orbit plane. Oe is the component of the path length L which lies in the direction of motion of the earth about the sun. In order to determine Oe it is necessary to find $\angle dOe$, Od and therefore Ob .

Returning to Figure 2-4 it can be seen that Ob is given by

$$Ob = \sqrt{(Oa)^2 + (ab)^2}$$

and

$$\theta'' = \angle bOA = \arctan(ab/Oa).$$

However, Oa and ab have yet to be determined. Their values are not obvious and therefore it is useful to refer first to Figures 2-7 and 2-8. From Figure 2-7a, Oa is given by

$$Oa = OA - AF' \tan(\tau_x)$$

where from Figure 2-7b, AF' is the vertical component of AF

given by

$$AF' = AF/\cos(T_y)$$

In this discussion T_x and T_y are the tilt angles of the x' and y' axis respectively with respect to the orbit plane.

These angles can easily be visualized by referring to Figure 2-7 where a line segment S lies on a plane which is tilted at an angle T to the horizontal. If S makes an angle θ with the x axis as shown then the angle between S and the horizontal plane is

$$T_s = \arcsin(\sin(\theta)\sin(T))$$

Thus T_x and T_y are given by

$$T_x = \arcsin(\sin(\angle AOA')\sin T)$$

$$T_y = \arcsin(\sin(\angle AOA' + 90^\circ)\sin T).$$

In a similar fashion ab is given by

$$ab = OC - BE' \tan(t_y)$$

where

$$BE' = BE/\cos(T_x).$$

The projection of Ob onto the orbit plane is Od

where

$$Od = Ob \cos(T_s)$$

where

$$T_s = \arcsin(\sin(\theta'' + \angle AOA')\sin(T)).$$

From Figure 2-4 it can be seen that

$$w = f(t_d) + H + \theta''$$

and from Figure 2-7

$$\omega' = \arctan ((\tan \omega) \cos T)$$

and

$$\chi = \omega' = t_d = dOe.$$

If $S' = Od$ then the components of L are $(S' \cos \omega', S' \sin \omega', \sqrt{L^2 - S'^2})$.

From this figure

$$Oe = S' \cos \chi$$

and has components

$$Oe (\cos t_d, \sin t_d, 0).$$

The cosine of the angle $\angle E O e$ between L and Oe is given by the dot product of these two vectors divided by the product of their magnitudes.

$$\cos (\angle E O e) = \frac{(Oe S' \cos t_d \cos \omega' + Oe S' \sin t_d \sin \omega' + \sqrt{L^2 - S'^2})}{L S' \cos \chi}$$

Thus, for the case in which the earth is considered to rotate about the sun the transit time along the path length L is given by

$$t = L/c \left\{ \frac{\beta \cos \angle E O e + \sqrt{\beta^2 \cos^2 (\angle E O e) + (1 - \beta^2)}}{1 - \beta^2} \right\} \quad (2-7)$$

where $\beta = v/c$.

The solar system is situated in the Orion arm of the Milky Way. The center of the galaxy is found beyond the Sagittarius arm while the Perseus arm forms the outer reaches of the galaxy. The Milky Way is not only rotating about its center with a tangential velocity (at earth) of 250 km/s but is also moving in a direction towards Perseus with a velocity

of 454 km/s. The resultant velocity V_r is 600 km/s in a direction 28 degrees below Perseus along the edge of the galaxy (See reference 27). In order to find the effects of possible ether drift due to this velocity it is necessary to find the angle between the resultant vector of V_r and the earth's orbital velocity and the path length L of the apparatus.

From the earth centered coordinate system at 0 hours (Ottawa) December 22 the vector towards Perseus V_p has the value

$$(454 \text{ km/s}, 45^\circ \text{ Lat.}, 37^\circ \text{ W of S}).$$

On the coordinate system from the solar plane the resultant vector of the addition of galactic rotation and motion towards Perseus has components

$$(-238.5, -316.5, 415) \text{ km/s.}$$

The velocity vector of the earth about the sun is given by

$$V_e = 30 \frac{\text{km}}{\text{s}} (\cos t_d, \sin t_d, 0).$$

This finally gives the resultant velocity vector V_R of the laboratory through the stationary ether

$$(-238.5 + 30 \cos (t_y), -316.5 + 30 \sin (t_d), 415) \text{ km/s}$$

with components

$$RX = -238.5 + 30 \cos (t_y) \text{ km/s}$$

$$RY = -316.5 + 30 \cos (t_y) \text{ km/s}$$

$$RZ = 415 \text{ km/s}$$

This vector can be written as

$$V_R = |V_R| (\cos (V_{RX}), \sin (V_{RY}), \sin (V_{RZ}))$$

where

$$|V_R| = \sqrt{(RX)^2 + (RY)^2 + (RZ)^2}$$

$$\cos(V_{RX}) = RX / \sqrt{(RX)^2 + (RY)^2}$$

$$\sin(V_{RY}) = RY / \sqrt{(RX)^2 + (RY)^2}$$

$$\sin(V_{RZ}) = \sqrt{V_R^2 - ((RX)^2 + (RY)^2)} / |V_R|$$

The cosine of the angle between V_R and L is given by the dot product of the two vectors. The vector L has components

$$(S' \cos \omega', S' \sin \omega', \sqrt{L^2 - S'^2})$$

where L has a magnitude of $|L|$ and $S' = 0d$. Taking a unit vector in the direction of V_R , the projection of L onto this vector is

$$\cos V_L = (S' \cos \omega' \cos V_{RX} + S' \sin \omega' \sin V_{RY} + \sqrt{L^2 - S'^2} \sin V_{RZ}) / |L|$$

Substituting the above values into equation 2-6 the transit time along the path length is given by

$$t = \frac{L}{C} \frac{\beta_r \cos V_L + \sqrt{(\beta_r \cos V_L)^2 + (1 - \beta_r^2)}}{1 - \beta_r^2} \quad (2-8)$$

where

$$\beta_r = \frac{V_R}{C}$$

The solar system is revolving about the center of the galaxy with a velocity of about 250 km/s. The center of the galaxy is in the direction towards the constellation Sagittarius. Based on the solar plane coordinate system, on 22 December, the velocity vector is approximately (15.7, 20.9, 248.6) km/s.

The sum of solar and galactic rotation velocities is $(15.7 + 30 \cos t_d, 20.9 + 30 \sin t_d, 248.6)$ km/sec.

This has components

$$R_x = 15.7 + 30 \cos t_d \text{ km/s}$$

$$R_y = 20.9 + 30 \sin t_d \text{ km/s}$$

$$R_z = 248.6 \text{ km/s}$$

Thus,

$$|V_R| = \sqrt{(R_x)^2 + (R_y)^2 + (R_z)^2}$$

$$\cos V_{RX} = R_x / \sqrt{(R_x)^2 + (R_y)^2}$$

$$\sin V_{RY} = R_y / \sqrt{(R_x)^2 + (R_y)^2}$$

$$\sin V_{RZ} = \sqrt{(V_R)^2 - (R_x)^2 - (R_y)^2} / |V_R|$$

The cosine of the angle between V_R and L is given by the dot products of the two vector. Taking a unit vector in the direction of V_R , the projection of L onto this vector is

$$\cos V_L = (S' \cos \omega' \cos V_{RX} + S' \sin \omega' \sin V_{RY} + \sqrt{L^2 - S'^2} \sin V_{RZ})$$

This finally gives a value for the transit time of

$$t = \frac{L}{C} \left\{ \beta_r \cos V_L + \frac{\sqrt{(\beta_r \cos V_L)^2 + (1 - \beta_r^2)}}{1 - \beta_r^2} \right\} \quad (2-9)$$

where

$$\beta_r = V_R / C.$$

Figure: 2-1 Diagram showing the transit time symbols for the TAC (Time to Amplitude Converter) method.

Figure 2-2: The transit time t for a signal along L at an arbitrary angle.

Figure 2-3: Laboratory Coordinates

Figure 2-4: Earth centered coordinates

Figure 2-5: Solar plane Coordinate system

$$Oa = OA - DF' \tan \tau_x$$

Figure 2-7a:

2-7b

$$\tau_s = \arcsin(\sin \theta \sin \tau)$$

$$\theta' = \arctan(\tan \theta \cos \tau)$$

Figure 2-8:

CHAPTER III

APPARATUS AND METHOD

1. Apparatus

In Chapter II, two first order ether search methods were discussed. The apparatus used to perform these experiments is described briefly here and in greater detail in Appendix 3. (See Figure 3-1).

The TAC (Time to Amplitude Converter) method uses two identical sets of electronics, each consisting of one 5 MHz oscillator, shaping and control logic and one TAC (Figure 3-2). Each set is mounted in a temperature controlled, shielded box on opposite ends of a rotating 4 meter arm. Mounted on each box is the necessary power regulators and temperature controlling devices. The output of each TAC is brought together to an ADC (Analog to Digital Converter) located on the rotating support shaft. An interface to transfer data to and from the computer (PDP 9/L) is also located on the shaft.

The entire rotating mechanical apparatus is referred to as the MGR (Merry-go-round). All power to the electronics and data, enters and leaves the MGR via a 16 ring commutator mounted above the shaft and a 2 ring commutator mounted on the lower end of the shaft. Data is received by the computer through a second interface. The computer also controls, through these interfaces, a DAC (Digital to Analog Converter) which in turn controls the frequency of one oscillator. This

Figure:3-1

Photograph showing an over all
view of the MGR.

Fig. 3-2 Basic arrangement of apparatus for the TAC Ether search method.

is necessary in order to place the output of the TAC's in range of the ADC. Of course the DAC is not used when actual data are being collected.

In the Beat Method (Figure 3-3), in one box are located a 5 MHz oscillator and shaping logic. In the other box are a similar 5 MHz oscillator, shaping logic and the beat detector logic. From this logic a 5 MHz clock signal and a beat period signal are generated and made available to the interface on the shaft. The beat period is then sent to the computer.

In both methods, accompanying each result, sent to the computer, is a number representing the position of the MGR arm in the laboratory. This number is generated by a position detector as described in Appendix 3.

2. TAC Method

In this method (see Figure 3-2) two identical oscillators were located at opposite ends of the MGR arm. Located along with each oscillator was the time interval measuring device which was the Ortec 457 time to amplitude converter (TAC) and the logic which shaped the oscillator output and alternated the stop signal to the TAC from each oscillator. The start input to each TAC came from its own oscillator while the stop input came from the other oscillator. Each TAC was operated at its maximum time sensitivity (50 ns full scale) and with its biased amplifier at maximum gain (10). Although they were matched TAC's fine adjustments were made so that each one had approximately the same calibration factor. Thus the output of each TAC located at the ends of the arm, A and B, was proportional to the time

Fig. 3-3 Basic arrangement of apparatus
for the Beat Ether search method.

intervals as given in equations 2-1 and 2-2.

The outputs which occurred alternately, due to the logic, were fed to an analog to digital converter (ADC). To put the signals on the center channel of the ADC two fine control (GR trombone lines) delay lines on the stop inputs of the TAC's were adjusted. The output of the ADC then went to the interface where the data lines were serialized and transmitted to the computer. Simultaneously with this the computer was also given the position of the MGR arm in the laboratory from the position detector. Each pair of results was subtracted from one another giving the result in equation 2-3 but as a function of position.

The circle of rotation of the MGR was divided up into eight equal sectors. Results collected in any one sector over a three hour period were held in the appropriate histogram. The histograms had a complicated shape, as the results in a 22.5 degree sector varied somewhat and over a three hour period even more so. However for this method this problem was never solved since the method itself had more basic problems.

Each oscillator was independent of the other. The consequence was that once their frequencies had been initially set to be almost equal, they were then free to behave in whatever manner they chose. To begin with; the electronic resolution of one TAC oscillator system was about 20 ps. Thus it was necessary to set the frequencies of the oscillators to be close enough so that an adequate amount of data could be collected as

they slowly drifted apart. About the smallest difference in oscillator periods that could be consistently obtained was 2×10^{-4} ps. This gives 10^5 periods or 2×10^{10} ps to reach 20 ps drift. Although the time to convert each event by the apparatus is only some 20×10^6 ps the computer could only handle and store events at a rate of 1 event in 10^8 ps. Thus only about 200 events could be stored before the drift became a problem. After this number of events it was then necessary to make a measurement of the drift and correct one oscillator by either increasing or decreasing its frequency by means of the DAC (digital to analog converter) and the fine frequency control on the oscillator. This would then cause the drift to reverse direction rapidly. The DAC setting had then to be changed again to stop the drift when the data was back on scale. It took several minutes to make this correction as many samplings of the results were necessary. All previously collected data had to be analysed so that they would be independent of any shift caused by the resetting by the DAC.

The above procedure was long and possibly questionable. Certainly trying to analyze the drift out of the data would be difficult and would require accurate measuring of the drift independently of other effects.

Finally the 8192 channel ADC based on the Northern Scientific NS624 with some modifications was never delivered. All of the previous tests were done using 1024 channel ADC's giving only ~ 5 ps/channel.

3. Beat Method

This method (see Figure 3-3) had a very low data rate which was its major drawback. A difference in periods of $\Delta p = .1$ ps was chosen as this gave a beat period of $\sim .4$ seconds. This was approximately .25 of the period of rotation of the MGR which was ~ 1.7 seconds. This gave a maximum difference between the β terms in equation 2-4. Only every second beat period was measured giving a data rate of 1 event per 0.8 seconds.

The sine wave outputs of the oscillators were shaped by the logic. The signal from end B travelled along the arm of the MGR to end A where it beat together with oscillator A. The beat period was determined by the J-K flip-flop and scaled against oscillator A (see pages A3-55 and 56). This number was serialized and transmitted to the computer together with the position of the arm in the laboratory. "A" end determined the origin of the position when it was pointing north. The direction of rotation of the arm was reversible. This was done periodically to ensure that any background pattern detected due to bearing and drive mechanism wear could be identified.

The DAC was used only to set the period difference between the oscillators to $\sim .1$ ps. Since the oscillators were very stable, once oscillator B's period was set to 200000.0 ps and the period difference .1 ps was set (either + or - since the beats could be measured either way) the DAC was used only every few days.

This method was more satisfactory than the TAC method.

since the oscillators were seldom corrected and there were much less electronics involved in the measurement. The electronic resolution was typically < 1 ps and the channel width was $\sim .1$ ps.

The equipment and computer could be checked three different ways. First the DAC number sent by the computer could be returned and checked. Secondly, an external clock of period .1 seconds for example, could be used instead of the beat data to test the scaler and other circuitry. This clock was a Tektronix Time Mark Generator type 184. Finally the data from Oscillator B could be run through a variable length transmission line whose length was uniformly changed during a beat period, thus simulating an ether effect.

Data using the beat method were collected on and off during the period between January 1976 and January 1977. The reasons for the "on and off" were equipment failure and the problems due to the erection of a local FM Station. This station's transmitter was moved in October 1976 allowing data collection over the ensuing couple of months.

As indicated earlier the beat period was approximately .4 seconds. The actual number read by the computer was the contents of a 4096 bit scaler which had counted a 5MHZ clock for the duration of a beat period. The overflow of this scaler (typically 488 times) was entered into the computer at the start of a data run. This was satisfactory since only the last three (and usually two digits) in the scaler varied. Once a run was started data were collected for about two

minutes. Then the mean value in each sector was determined and the overall mean over 360° was determined. This last value is independent of any ether effect. The difference between each sector mean and the overall mean was then stored. These numbers (changes in beat period ΔP) then are presumedly independent of irregular drifts in the oscillators and associated electronics and contain only ether information plus whatever background was induced by mechanical or electromagnetic effects. The procedure was repeated every two minutes until three hours elapsed. At this time the data was printed out and stored on magnetic tape. The mean value of the overall mean plus the overflow was calculated producing the average beat period as was the mean value and standard error of each sector producing the changes in beat period*. This was repeated every three hours until the equipment broke down or the laboratory temperture went out of range.

Experimental changes in beat periods ΔP (β , S, H, D) were collected in eight sectors (S) every three hours (H) for periods of days (D). Corresponding to each S, H and D, a theoretical change in beat period ΔT (β , S, H, D) was calculated using one of the models discussed in Chapter II. For each sector and day a chi squared fitting procedure was used to determine the value of β in the theoretical model. For each model the theoretical β was multiplied by an amplitude A which was the first fitting parameter. The calculated chi squared was

$$\chi^2 (S,D) = \sum_H \left(\frac{\Delta P(\beta, S, H, D) - \Delta T(\beta, S, H, D) - B(S,D)}{E(\beta, S, H, D)} \right)^2$$

B (S,D) was the background and is the second fitting parameter. The background, caused by mechanical vibrations and electromagnetic effects, was assumed to remain constant for at least twenty four hours. E (β,S,H,D) was the experimentally measured error.

A and B were found by finding their values which minimized χ^2 . The weighted mean value and error of the A's were calculated. The product of this with the theoretical β determined the experimental value of β. A value for A was determined for each of the three models.

$$* \Delta P(s) = P_B(s) - \sum_s^m P_B(s)/m$$

where P(s) is the measured beat period in each sector and m is the number of sectors.

From equation 2-4 where $\Delta t(s) = t_f - t_i$

$$\begin{aligned} \Delta P(s) &= nP_B + \Delta t(s) - \sum_s^m \frac{(nP_B + \Delta t(s))}{m} \\ &= \Delta t(s) \end{aligned}$$

The theoretical value of $\Delta t(s)$ is determined by use of equation 2-7, 2-8, 2-9.

CHAPTER IV

DATA AND ANALYSIS

The following table (4-1) contains sample raw data in the form of measured changes in beat period and the corresponding standard error and the expected changes in beat period based on the previously developed theories. Figure 4-1 shows the beat period drift as measured every three hours over a four day period. It is this long period drift which is removed from the data by collecting data in two minute intervals and then saving only the differences between each sector's value and the overall mean as described in Chapter III. Figure 4-2 shows the change in beat period as measured for position (or sector) North in the laboratory, every three hours for four consecutive days. The data is redrawn in Figure 4-3 after the background (see Chapter III) was removed. If there was any periodic effect it should appear in this figure. Figures 4-4, 4-5 and 4-6 show the expected theoretical results based on theories 1, 2 and 3 respectively.

Figure 4-7 shows the data for all eight positions or sectors at two different times in the day, while Figure 4-8 shows the same data with the background removed. Figures 4-9, 4-10, 4-11 show the corresponding theoretical data for theories 1, 2 and 3 respectively.

Table 4-2 contains the corresponding values of amplitude (see Chapter III) which gave the best fits to the data using the Chi Squared fitting procedure, for both theories. Each

entry is the mean value (and standard error) for each of the corresponding days run and is thus based on eight values, one for each sector. At the bottom of the table is the calculated weighted mean and error for each theory. Figures 4-12, 4-13 and 4-14 show the fitted amplitudes for all three theories. No periodic effects are observed.

Finally, Table 4-3 shows some fitted amplitudes as obtained from January 1976. At the bottom of this table is the calculated weighted mean and error for each theory.

Table 4-1: Sample data showing experimentally measured changes in beat period and the corresponding error and the expected changes based on the three models. All units in microseconds.

16 DEC. 77 22:30-01:30 HOURS 400179.11 (beat period)

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.820	0.224	1.075	-79.720	-1.237
	0.429	0.240	-0.754	-23.865	1.096
W	-2.272	0.229	-3.365	46.189	-1.200
	-0.681	0.232	-4.705	44.510	-30.390
S	0.338	0.238	-1.075	16.732	-41.754
	0.445	0.240	0.754	23.712	1.853
E	-1.573	0.234	3.364	17.051	40.394
	-0.560	0.159	4.705	-44.374	27.704

01:30-04:30 HOURS 400183.77					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.400	0.154	-1.614	-64.404	-7.854
	0.277	0.157	-2.189	26.814	-4.086
W	-1.701	0.167	-3.817	79.091	-14.548
	-0.415	0.163	-1.304	59.161	-31.558
S	-0.030	0.162	1.614	22.186	-17.030
	0.297	0.154	2.189	3.466	26.026
E	-1.277	0.159	3.817	-40.604	37.238
	-0.357	0.298	1.304	-86.767	11.554

04:30-07:30 HOURS 400187.29					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	4.177	0.316	-2.802	-14.298	-18.978
	1.022	0.317	-2.763	72.761	-6.662
W	-2.686	0.300	-0.655	84.755	-11.657
	-0.414	0.316	2.445	37.805	-14.811
S	0.471	0.313	2.802	-3.112	9.201
	0.380	0.317	2.763	-27.883	36.046
E	-2.073	0.305	0.655	-68.883	20.56
	-0.612	0.374	-2.445	-78.711	-59.881

07:30-10:30 HOURS 400191.43					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.697	0.341	-2.813	37.919	-28.114
	0.673	0.374	-0.767	86.532	-5.393
W	-1.607	0.352	2.282	59.734	5.811
	-0.912	0.387	3.819	-6.796	10.236
S	0.170	0.341	2.813	-47.405	21.564
	0.099	0.370	0.767	-52.120	25.748
E	-1.292	0.363	-2.282	-51.072	0.165
	-0.407	0.301	-3.819	-24.769	28.892

16 DEC. 77 10:30-13:30 HOURS 400194.62

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.654	0.297	- 1.124	61.994	-29.814
	0.884	0.296	1.654	61.032	- 0.519
W	- 2.429	0.304	3.636	18.656	27.512
	- 0.473	0.306	3.480	49.006	28.576
S	- 0.091	0.312	1.124	-84.674	12.839
	0.442	0.318	- 1.654	-54.428	1.681
E	- 1.748	0.319	- 3.636	2.023	-12.086
	- 0.185	0.264	- 3.480	42.976	-29.636

13:30-16:30 HOURS			400196.55		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.785	0.276	1.404	61.184	-10.152
	0.598	0.275	3.287	10.312	4.773
W	- 2.183	0.263	3.317	-29.165	29.794
	- 0.762	0.254	1.646	-63.707	29.682
S	0.246	0.257	- 1.404	-75.494	1.211
	- 0.030	0.250	- 3.287	-33.946	-22.404
E	- 1.432	0.247	- 3.317	44.856	-19.995
	- 0.410	0.264	- 1.646	85.290	-13.567

16:30-19:30 HOURS			400197.29		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.775	0.279	3.857	21.682	6.412
	0.356	0.274	3.180	-35.771	7.237
W	- 2.141	0.282	1.519	-43.984	22.340
	- 0.762	0.259	- 1.181	-42.200	13.018
S	0.003	0.268	- 3.857	-39.761	-19.514
	0.066	0.261	- 3.180	- 2.949	-32.593
E	- 1.235	0.267	- 1.518	63.820	7.883
	- 0.236	0.289	1.180	77.505	10.026

19:30-22:30 HOURS			400197.56		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.819	0.299	4.411	-36.805	10.105
	0.438	0.322	0.947	-49.871	5.805
W	- 2.107	0.304	- 0.625	-11.571	11.154
	- 0.915	0.287	- 4.381	2.515	-11.94
S	0.489	0.299	- 4.411	- 1.529	-37.400
	- 0.270	0.297	- 0.947	21.139	-22.382
E	- 1.304	0.289	0.625	53.603	18.777
	- 0.376	0.000	4.381	23.685	27.052

17 DEC. 77 22:30-01:30 HOURS 400196.67

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.297	0.282	2.594	-80.307	- 5.263
	0.915	0.294	0.120	-22.840	- 2.738
W	- 2.192	0.306	- 2.295	47.167	-12.222
	- 0.184	0.287	- 5.182	45.251	-33.250
S	- 0.270	0.278	- 2.594	16.801	-24.952
	0.279	0.286	- 0.120	23.471	20.078
E	- 1.774	0.289	2.294	15.579	39.770
	- 0.065	0.353	5.182	-45.831	17.450

01:30-04:30 HOURS			400197.14		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.771	0.314	- 0.441	-63.487	-15.725
	0.379	0.335	- 1.607	28.090	- 6.328
W	- 2.066	0.302	- 4.674	79.593	-14.223
	- 0.423	0.337	- 3.406	59.063	-20.986
S	0.255	0.316	0.441	21.956	2.566
	0.329	0.335	1.607	2.778	35.192
E	- 1.634	0.312	4.674	-41.733	26.220
	- 0.397	0.407	3.407	-87.205	- 5.333

04:30-07:30 HOURS			400197.52		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.623	0.427	- 2.288	-12.940	-26.088
	0.775	0.409	- 3.325	73.550	- 6.222
W	- 1.950	0.410	- 2.760	84.489	- 0.160
	- 0.486	0.405	0.515	36.920	3.149
S	0.055	0.421	2.287	- 4.040	20.106
	0.274	0.423	3.325	-28.612	30.530
E	- 1.925	0.422	2.761	-69.009	5.617
	- 0.575	0.330	- 0.515	-77.880	-25.440

07:30-10:30 HOURS			400197.57		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.786	0.322	- 3.384	38.919	-30.234
	0.560	0.346	- 2.399	86.365	- 2.045
W	- 1.820	0.323	0.320	58.855	21.666
	- 0.511	0.350	2.972	- 7.944	24.762
S	0.294	0.314	3.384	-48.485	17.444
	- 0.388	0.343	2.399	-52.463	9.277
E	- 1.761	0.311	- 0.320	-50.119	-10.006
	- 0.055	0.160	- 2.972	-23.151	-31.356

17 DEC. 77 10:30-13:30 HOURS 400195.48

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.742	0.170	- 2.712	62.057	-15.965
	0.311	0.174	- 0.124	60.010	3.396
W	- 2.017	0.162	2.601	17.676	30.506
	- 0.363	0.166	3.914	-49.748	31.390
S	- 0.213	0.173	2.712	-85.270	5.912
	0.351	0.164	0.124	-54.187	-16.490
E	- 1.713	0.167	- 2.601	3.489	-19.488
	- 0.073	0.346	- 3.914	44.430	-19.437

13:30-16:30 HOURS			400192.22		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.314	0.336	- 0.595	60.679	2.695
	0.413	0.353	2.158	9.036	6.909
W	- 1.583	0.342	3.480	-30.059	25.098
	- 0.561	0.339	3.178	-63.610	19.191
S	- 0.639	0.340	0.595	-74.849	-13.408
	0.330	0.360	- 2.158	-33.253	-31.660
E	- 1.655	0.345	- 3.480	45.596	-13.348
	0.599	0.334	- 3.177	85.728	3.383

16:30-19:30 HOURS			400192.14		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	4.383	0.347	2.347	20.378	10.662
	0.391	0.319	3.278	-36.559	6.636
W	- 2.132	0.324	2.602	-43.734	14.343
	- 0.978	0.325	0.893	-41.315	- 4.864
S	0.676	0.337	- 2.347	-38.782	-33.358
	- 0.356	0.344	- 3.278	- 2.223	-27.162
E	- 1.592	0.300	- 2.602	63.928	10.546
	- 0.726	0.220	- 0.893	76.676	23.580

19:30-22:30 HOURS			400187.82		
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.272	0.221	4.469	-38.145	3.276
	0.610	0.221	1.899	-49.702	2.619
W	- 2.012	0.222	0.749	-10.330	4.508
	- 0.534	0.217	- 2.888	3.663	-26.576
S	0.113	0.207	- 4.469	- 0.785	-42.218
	0.286	0.206	- 1.899	21.486	5.744
E	- 1.461	0.210	- 0.749	53.015	38.166
	- 0.289	0.000	2.888	22.066	29.424

18 DEC. 77 22:30-01:30 HOURS 400186.39

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	4.018	0.232	2.660	-81.920	-11.888
	1.100	0.206	1.778	-19.675	-5.514
W	-2.419	0.233	2.794	50.070	-15.493
	-0.781	0.225	0.039	47.377	-26.958
S	-0.127	0.221	-2.660	16.900	-6.323
	0.289	0.219	-1.778	22.667	32.056
E	-1.641	0.224	-2.794	11.148	32.098
	-0.603	0.245	-0.039	-50.108	2.754

01:30-04:30 HOURS 400189.63					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.774	0.233	2.491	-60.620	-23.036
	0.542	0.238	1.618	31.899	-6.661
W	-1.903	0.240	-0.859	81.003	-6.328
	-0.265	0.252	-3.689	58.641	-5.489
S	-0.020	0.246	-2.491	21.143	16.195
	-0.293	0.247	-1.618	0.673	34.436
E	-1.698	0.255	0.859	-45.015	12.566
	-0.396	0.286	3.689	-88.336	-19.880

04:30-07:30 HOURS 400197.13					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.632	0.268	1.581	-8.861	-29.806
	0.659	0.252	-0.487	75.799	-3.735
W	-1.810	0.221	-3.758	83.581	14.274
	-0.159	0.284	-4.038	34.182	18.695
S	0.303	0.247	-1.581	-6.891	20.744
	-0.413	0.253	0.487	-30.774	17.661
E	-2.044	0.264	3.758	-69.221	-6.008
	-0.322	0.306	4.038	-75.220	-31.398

07:30-10:30 HOURS 400210.24					
POSITION	DATA	ERROR	THEORY 1	& 2	3
N	4.071	0.309	-0.453	41.816	-22.748
	0.792	0.312	-2.864	85.730	1.579
W	-1.863	0.334	-4.065	56.159	30.396
	-0.574	0.283	-2.363	-11.383	31.350
S	0.105	0.314	0.453	-51.700	10.154
	-0.012	0.309	2.863	-53.406	-8.381
E	-1.643	0.310	4.065	-47.134	-16.587
	-0.657	0.289	2.363	-18.254	-25.148

18 DEC. 77 10:30-13:30 HOURS

400219.06

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.824	0.294	- 2.697	62.091	- 2.840
	0.280	0.310	- 3.624	56.850	6.155
W	- 1.867	0.301	- 2.654	14.767	27.762
	- 0.265	0.299	0.059	-51.873	25.124
S	- 0.467	0.311	2.697	-86.957	- 6.218
	- 0.246	0.296	3.624	-53.383	- 28.474
E	- 1.352	0.313	2.655	7.902	-17.831
	0.161	0.275	- 0.059	48.702	- 4.737

13:30-16:30 HOURS

400229.18

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.523	0.301	- 4.016	59.016	9.647
	0.171	0.286	- 2.765	5.225	7.189
W	- 2.538	0.264	- 0.376	-32.600	18.189
	- 0.018	0.299	2.482	-63.188	3.714
S	- 0.114	0.287	4.016	-72.829	-27.402
	- 0.200	0.296	2.765	-31.140	-30.952
E	- 1.213	0.261	0.376	47.747	1.284
	0.413	0.288	- 2.482	86.865	17.952

16:30-19:30 HOURS

400239.24

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.686	0.278	- 3.631	16.396	7.381
	0.328	0.299	- 0.419	-38.805	4.268
W	- 2.535	0.315	1.685	-42.817	7.299
	- 0.622	0.331	4.141	-38.579	-20.464
S	0.010	0.291	3.631	-35.836	-40.992
	0.520	0.286	0.419	- 0.068	-14.184
E	- 1.643	0.304	- 1.685	64.146	29.560
	0.213	0.138	- 4.141	74.022	29.504

19:30-22:30 HOURS

400245.75

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.763	0.138	- 0.740	-42.106	- 2.878
	0.809	0.160	1.574	-49.052	- 0.987
W	- 2.319	0.140	2.703	- 6.506	- 7.868
	- 0.621	0.162	3.715	7.098	-33.172
S	0.105	0.136	0.740	1.373	-33.590
	- 0.096	0.153	- 1.574	22.450	11.921
E	- 1.610	0.138	- 2.703	51.168	41.116
	- 0.117	0.000	- 3.715	17.158	23.206

19 DEC. 77 22:30-01:30 HOURS 400250.60

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.713	0.169	1.224	-82.409	-18.978
	0.766	0.184	1.548	-18.593	-6.662
W	-2.071	0.180	3.732	51.026	-11.288
	-0.687	0.176	2.542	48.051	-14.811
S	0.360	0.179	-1.224	16.896	9.213
	-0.137	0.191	-1.548	22.373	36.046
E	-1.840	0.174	-3.732	9.669	20.560
	-0.201	0.169	-2.542	-51.501	-11.976

01:30-04:30 HOURS 400256.15

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.765	0.163	2.461	-59.628	-28.114
	0.828	0.151	2.294	33.161	-5.393
W	-2.084	0.144	1.488	81.439	5.811
	-0.501	0.143	-1.722	58.456	10.236
S	-0.315	0.155	-2.461	20.832	21.564
	-0.149	0.151	-2.294	-0.041	25.748
E	-1.662	0.150	-1.488	-46.071	0.165
	-0.062	0.136	1.722	-88.652	-28.892

04:30-07:30 HOURS 400259.43

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.815	0.134	2.562	-7.501	-29.814
	0.926	0.163	1.196	76.508	0.519
W	-2.132	0.137	-2.052	83.242	27.512
	-0.686	0.129	-3.885	33.243	28.576
S	-0.020	0.128	-2.562	-7.862	12.893
	-0.020	0.144	-1.196	-31.484	1.681
E	-1.733	0.128	2.051	-69.236	-12.086
	-0.040	0.130	3.884	-74.280	-29.636

07:30-10:30 HOURS 400259.23

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.996	0.147	1.258	42.747	-10.152
	0.928	0.145	-1.408	85.474	4.773
W	-2.246	0.145	-3.797	55.243	29.794
	-0.565	0.141	-3.567	-12.526	29.683
S	-0.259	0.125	-1.258	-52.761	1.221
	0.167	0.130	1.408	-53.692	-22.404
E	-1.743	0.126	3.797	-46.098	-19.995
	-0.220	0.188	3.567	-16.609	-13.567

19 DEC. 77 10:30-13:30 HOURS 400260.29

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	4.251	0.181	- 1.094	62.051	- 6.412
	1.057	0.190	- 3.191	55.768	7.237
W	- 1.662	0.180	- 3.635	13.809	22.340
	- 0.947	0.188	- 1.854	-52.546	13.018
S	- 0.439	0.207	1.093	-87.483	-19.593
	- 0.334	0.186	3.191	-53.088	-32.514
E	- 1.684	0.212	3.635	9.377	7.883
	- 0.215	0.246	1.854	50.093	10.026

13:30-16:30 HOURS 400259.98

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.749	0.229	- 3.322	58.412	10.105
	0.883	0.228	- 3.530	3.961	5.805
W	- 1.764	0.220	- 2.011	-33.400	11.154
	- 1.022	0.226	0.682	-63.003	-11.940
S	- 0.078	0.237	3.322	-72.129	-37.400
	- 0.285	0.208	3.531	-30.426	-22.382
E	- 1.705	0.236	2.011	48.441	18.777
	0.154	0.221	- 0.682	87.184	27.052

16:30-19:30 HOURS 400258.33

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.877	0.230	- 4.425	15.048	- 1.238
	1.075	0.233	- 1.935	-39.513	1.096
W	- 1.898	0.208	0.267	-42.455	- 1.200
	- 0.603	0.230	3.312	-37.641	-30.390
S	- 0.198	0.224	4.425	-34.852	-41.754
	- 0.261	0.223	1.935	0.642	1.853
E	- 1.786	0.213	- 0.267	64.183	40.394
	- 0.239	0.280	- 3.312	73.083	27.704

19:30-22:30 HOURS 400256.38

POSITION	DATA	ERROR	THEORY 1	& 2	3
N	3.919	0.262	- 2.816	-43.405	- 7.854
	1.292	0.267	0.532	-48.787	- 4.086
W	- 1.469	0.278	2.083	- 5.199	-14.548
	- 0.387	0.250	4.793	8.238	-31.558
S	- 0.522	0.268	2.816	2.067	-17.030
	- 0.280	0.261	- 0.532	22.744	26.026
E	- 1.973	0.264	- 2.083	50.525	37.328
	- 0.468	0.000	- 4.793	15.508	11.554

Figure; 4-1 Beat Period drift as measured every three hours over four days.

Figure: 4-2

Change in Beat Period of Position North
as measured every three hours.

4-13

Figure: 4-3 Change in Beat Period of Position North after background removed.

Figure: 4-4

Theoretical changes in Beat Period
as given by theory 1.

Figure: 4-5

Theoretical changes in Beat Period
as given by theory 2.

Figure: 4-6 Theoretical changes in Beat Period as given by theory 3.

4-17

16 Dec.
00:00 Hours

16 Dec.
06:00 Hours

Figure: 4-7

Change in Beat Period of all eight
positions at 00:00 and 06:00 hours
for December 16 1976

Figure: 4-8

Change in Beat Period of all eight positions at 00:00 and 06:00 hours for December 16 1976 after background removed.

4-19

16 Dec.
00:00 Hours

16 Dec.
06:00 Hours

Change in Beat Period (microseconds)

10
8
6
4
2
0
-2
-4
-6
-8
-10

N

W

S

E

N

W

S

E

Figure: 4-9

Theoretical change in Beat Period
as given by theory 1.

4-20

16 Dec.
00:00 Hours

16 Dec.
06:00 Hours

Figure: 4-10 Theoretical change in Beat Period
as given by theory 2.

4-21

16 Dec.
00:00 Hours

16 Dec.
00:00 Hours

Figure: 4-11

Theoretical change in Beat Period
as given by theory 3.

Table 4-2: Fitted amplitudes to the data in Table 4-1

16 Dec. 1976

Position	Background	Amplitude	Amplitude	Amplitude
		1	2	3
N	3.677 $\pm$.090	-.0047 $\pm$.046	.0011 $\pm$.002	-.0009 $\pm$.007
	.498 .094	-.0765 .077	.0030 .003	-.0104 .013
W	-2.050 .129	-.0333 .033	.0010 .002	-.0069 .010
	-.585 .066	-.0221 .035	.0020 .002	-.0025 .007
S	.122 .070	-.0321 .037	.0003 .002	-.0027 .007
	.239 .071	.0420 .055	.0011 .002	.0049 .008
E	-1.445 .093	-.0092 .012	.0016 .002	.0005 .006
	-.394 .048	-.0131 .043	.0008 .002	.0012 .007

17 Dec.

N	3.702 .110	-.0293 .039	.0015 .003	.0009 .007
	.476 .081	.0337 .061	-.0008 .003	-.0193 .014
W	-1.995 .062	-.0122 .054	-.0005 .003	.0026 .008
	-.453 .077	-.0325 .041	.0013 .003	.0004 .007
S	-.058 .135	-.0153 .045	.0013 .002	-.0031 .008
	.178 .108	-.0003 .022	.0003 .002	.0010 .008
E	-1.715 .029	-.0166 .016	.0013 .002	.0029 .008
	-.153 .126	-.0263 .041	.0017 .002	-.0035 .007

18 Dec.

N	3.794 .069	.0322 .041	-.0011 .003	-.0028 .008
	.591 .117	-.0819 .036	.0001 .003	-.0433 .025
W	-2.147 .117	-.0955 .024	.0032 .001	.0070 .009
	-.366 .100	-.0193 .032	-.0015 .002	.0077 .009
S	-.046 .079	-.0259 .051	.0016 .003	-.0001 .007
	-.048 .121	-.0388 .070	.0049 .002	-.0004 .007
E	-1.632 .090	-.0206 .063	.0036 .002	.0001 .008
	-.204 .149	-.0907 .027	.0050 .001	.0096 .012

19 Dec.

N	3.888 .062	-.0165 .051	.0025 .001	.0035 .010
	.913 .036	-.0310 .031	.0004 .001	.0102 .015
W	-2.029 .072	-.0066 .029	-.0014 .001	-.0023 .008
	-.679 .062	-.0076 .036	.0026 .001	.0003 .006
S	-.169 .084	-.0044 .031	.0019 .001	.0021 .008
	-.074 .063	-.0149 .029	-.0012 .001	-.0017 .007
E	-1.730 .019	.0051 .024	-.0002 .001	-.0020 .007
	-.125 .042	.0048 .023	-.0001 .001	-.0008 .008

Mean amplitude

-.0164 $\pm$.174 .0012 $\pm$.010 -.0002 $\pm$.025

Figure: 4-12 Fitted amplitude based on theory 1

Figure: 4-13 Fitted amplitudes based on theory 2

Figure: 4-14 Fitted amplitudes based on theory 3

Table 4-3: Fitted amplitudes for 1976 & 1977

4-26

Year	Month	Day	Amplitude 1		Amplitude 2		Amplitude 3			
1976	Jan.	21	-.00646	.106	-.00290	.00520	.00045	.0094		
		22	-.09300	.108	.00929	.00872	-.01015	.0115		
	May	25	.04310	.079	.00210	.00400	.00425	.0042		
		26	.12600	.211	-.00050	.00500	-.00011	.0094		
	Sept.	11	.04600	.030	-.00100	.00735	.00531	.0090		
		16	-.00626	.030	.04330	.0110	.00014	.0065		
	Dec.	14	-.02890	.011	-.00010	.00030	.00097	.0009		
		15	.0088	.019	.00010	.00130	-.00330	.0034		
		16	-.0186	.012	.00135	.00060	-.00099	.0089		
		17	-.0124	.0075	.00076	.00034	.00027	.0139		
		18	-.0221	.0210	.00195	.00920	.00119	.0181		
		19	-.0089	.0042	.00056	.00056	-.00002	.0069		
		21	-.0103	.0063	-.00003	.00053	-.00270	.0019		
	1977	Jan.	25	.0345	.096	-.00725	.00620	-.00465	.0096	
			27	-.0703	.11	.00325	.00422	.00921	.0103	
			31	.0343	.079	-.00500	.00360	.00850	.0102	
		Feb.	1			-.00812	.00880	-.00500	.0180	
			3			-.01040	.00770	-.00778	.0150	
			4			.00300	.00950	.01390	.0137	
5			-.0880	.067	-.00125	.00825	-.00218	.0087		
16			.0216	.101	.00650	.01200	-.00312	.0120		
17			.0590	.049	.00450	.01170	.00050	.0167		
18			-.0316	.075	.00775	.03500	-.00420	.0189		
19			.0415	.150	.00025	.00550	-.01188	.0119		
20			-.0307	.096	.00300	.00195	-.00897	.0122		
21			.0405	.157	-.00350	.00284	.00367	.0210		
22			-.0648	.078	.00263	.00550	-.00063	.0110		
23			-.0011	.150	-.00838	.00670	-.00927	.0164		
Mean amplitude			-.0108 +/-	.053	.00036 +/-	.00572	.00016 +/-	.0128		

CHAPTER V

CONCLUSIONS

From Table 4-3 amplitudes for theories 1, 2 and 3 were obtained. For the case of simple rotation of the earth about the sun the theoretical value of v (the ether velocity) is 30 km/s. The experiment obtains a value of v given by 30 km/s $\times$ amplitude 1 = -324 ± 1620 m/s. For the more complicated case which includes motion through space, the theoretical value of v is 600 km/s and this experiment gives 600 km/s $\times$ amplitude 2 = 219.6 ± 3432 m/s. Finally for the case of solar and galactic rotation only $v = 41.6 \pm 3328$ m/s.

These results would seem to indicate that if there is an ether velocity, that it must be smaller than a few hundred meters/second. The value of β for theory 1 is experimentally, -1.08×10^{-6} for theory 2 is 7.32×10^{-7} and for theory 3 is 1.38×10^{-7} . Table 5-1 gives a list of ether experiments and the obtained β values. This present experiment although not as accurate as other first order experiments is comparable to second order tests. The experiment is unique in that it does have the ability to distinguish between contraction and relativity theory. Were the contraction theory correct then the observed amplitudes would have been one half of that theoretically calculated. The observed amplitudes are substantially less and taking into account their error they are consistent with zero.

The major source of error was vibrations in the driving mechanism. The instabilities caused the observed

background pattern to vary more frequently than the twenty-four hour period necessary for the analysis. It will be recalled that to remove background it was necessary to assume that it did not vary in a twenty four hour period.

The only way properly to remove the background would be to use accelerometers on the MGR arms and calibrate them so that their information might be used to correct the oscillator's period thus removing acceleration effects.

The experiment would also be improved by using a modulated laser instead of the transmission line. This would remove any doubts as to the validity of the experiment due to impedances in the line and its connections. The magnetostrictive effects on the laser might also be used to calibrate the apparatus since by placing a variable magnetic field near the laser the apparent beat period could be changed by known amounts. Finally to overcome any ether drag effects the experiment would best be performed in free space. However it is not likely that the methods used here can be improved by more than an order of magnitude.

SECOND ORDER EXPERIMENTS

Observer	Year	Place	β
Michelson	1881	Potsdam	$.5 \times 10^{-4}$
Michelson and Morley	1887	Cleveland	.1
Morley and Miller	1902-4	Cleveland	.08
Miller	1921	Mt. Wilson	.19
Miller	1923-4	Cleveland	.12
Miller	1924	Cleveland	.08
Tomaschek	1924	Heidelberg	.19
Miller	1925-6	Mt. Wilson	.2
Kennedy	1926	Pasadena and Mt. Wilson	.1
Illingworth	1927	Pasadena	.05
Piccard and Stahel	1927	Mt. Rigi	.18
Michelson, et al.	1929	Mt. Wilson	.075
Joos	1930	Jena	.037
Essen	1955	Teddington	.003
Cedarholm and Townes	1959	New York	.001

FIRST ORDER EXPERIMENTS

Cedarholm and Townes	1958	New York	$.001 \times 10^{-4}$
Champeney, et al.	1963	Birmingham	.0005
Turner and Hill (29)	1963	Princeton	.0073
Cialdea	1972	Rome	.0003
King (1)	1977	Ottawa	.01
King (2)	1977	Ottawa	.007
King (3)	1977	Ottawa	.001

Table 5:1: Ether Search Experiments up to 1977.

APPENDIX 1

Michelson and Morley; 1887 Experiment

In this experiment fringe shifts (measured in divisions of a micrometer screw where 50 divisions = 1 fringe width of sodium light) were recorded in 16 sectors as the interferometer was rotated through 2π radians. Figure A1-1 shows the fringe shifts for each sector at Noon. In this figure a constant drift is observed for each of the three days data. The mean for each sector is shown. In Figure A1-2 the difference between each mean result in A1-1 and the shown drift line is plotted. The expected form of the results for this figure is two cycles of a sine wave. Because of this the results for each cycle may be added together as shown in Figure A1-3.

Figures A1-4, 5 and 6 represent the data for 6 PM observations. From Figure A1-3 and 6 Michelson and Morley concluded that the relative velocity of earth and ether was about $1/6$ of the earth's orbital velocity. Due to the large errors in this experiment no acceptable fits to the theoretical models, as described in Chapter II, could be found. From these results, several possible conclusions may be drawn. First, that the theoretical models are wrong or second that the experiment was too susceptible to vibration and temperature effects thus producing a random pattern. The later seems the most reasonable.

AI-2

Noon 1887

Figure: A1-1 Michelson and Morley data July 1887
 Noon observations.

Figure: A1-2 Michelson and Morley data July 1887
 Noon observations with drift removed

Figure: A1-3 Michelson and Morley data July 1887
Noon observations with drift removed
half cycle shown.

Figure: A1-4 Michelson and Morley data July 1887
6 PM. observations

Figure: A1-5 Michelson and Morley data July 1887
6 PM observations with drift removed

Figure: A1-6 Michelson and Morley data July 1887
6 PM observations with drift removed
half cycle shown.

APPENDIX 2

D.C. Miller: 3 AM, 23 September, 1926 Experiment

D.C. Miller's experiments were performed with great care so as to minimize environmental and mechanical hazards. Much of his data showed very distinct periodic effects such as the data presented here. Data was collected in sixteen sectors as in Michelson's experiment. Figure A2-1 shows the uncorrected data while Figure A2-2 shows the corrected full cycle data. This data has an inverted symmetry about position 8. This in no way resembles two cycles of a sine wave. In spite of this the sum of the two halves about 8 does produce a sine wave as shown in Figure A2-3. From data such as this, Miller concluded that an ether velocity did exist.

The data in A2-2 does not fit any of the models in Chapter II. However that in A2-3 does fit a sine as expected from the simple model of rotation about the sun. This data though does not fit the model since the sine is shifted by a phase of about 40° . It is more likely that the effect is caused by vibrations or temperature fluctuations.

2

Figure: D.C. Miller's data for 3 AM 23 Sept.
A2-1 • 1926 uncorrected for drift.

Figure: A2-2 D.C. Miller's data for 3 AM 23 Sept.
1925 corrected for drift and scale.

Figure: A2-3 D.C. Miller's data for 3 AM 23 Sept.
1925 corrected for drift and scale,
half cycle shown.

Appendix 3: Apparatus

Mechanical	A3-1
Power	A3-9
Electronics	A3-39
Interface	A3-71
Temperature	A3-78

Apparatus: Mechanical

The mechanical parts of the apparatus were designed with several constraints in mind. Of course it was desirable to have the longest possible path length for the signals to traverse through the ether. However, costs and mechanical stability were of prime concern. The longer the path length the more costly would any rotating apparatus become and its stability would be more difficult to maintain. Undesirable modes of oscillation could be easily set up in a long rotating arm, thus requiring more structural materials. The problem was simplified by requiring the apparatus to fit into 1/4 of the laboratory in which the experiment was to be performed. This set the arm radius to be 81". The maximum load on the ends of the arms had to be set. This was determined by overestimating the weight of any possible electronics and the weight of their housings. Arbitrarily this was chosen to be 50 lbs.

To obtain very little vibration on the MGR with rapid damping of vibrations, the MGR was designed with two arms, one resting on top of the other on inflated tires, (Figure 3-1). There was no other direct connection between the two. (All the electronic apparatus was built upon the top arm). This eliminated most horizontal vibrations. A horizontal impulse of about 10 N-sec damped out almost completely in 3 seconds.

The arms are made of aluminum, 12" wide and 3/8" thick. The bottom arms are attached to a 12" diameter

Figure A3-1: Upper arm of the MGR is shown riding on inflated inner tubes. This method of support reduced vibrations from the lower arm reaching the upper arm.

3/8" thick aluminum plate which in turn is attached to a 4" OD aluminum shaft, 23" long. Two aluminum tubes 1-1/2" in diameter come out from near the base of the shaft to provide support to the arms as shown (Figure 3-2).

A vertical impulse of 10 N-sec takes almost 10 seconds to die out completely thus it is very important that there be very little vibration in the supporting shaft and bearings. The inside steel shaft has three bearings, one cone, one thrust and one lateral.

The support shaft is welded to a large base in the shape of a cross. Each section of the cross is an aluminum channel 36" long, 5" wide, 2-1/2" high. A leveling screw, which also bolts the section to the floor of the laboratory, is located at the end of each section.

At the base of the 4" shaft is located the copper commutator (see Figure 3-2) and above this is the 6" driving gear. The power from the commutator is brought up through the driving gear to a AC outlet box mounted on the side of the 4" shaft.

At the top of the 4" shaft are mounted 4 support rods 9/10" diameter and 8" long. They support a second 12" diameter plate above the top arms. Mounted to this plate and concentric with the support shaft is the commutator for the precision power supplies, (see Figure 3-2). The central shaft of this commutator is connected to a beam which passes over the laboratory by a 1-1/2 dia., 48" long plastic pipe.

Mounted on the end of each top arm is an aluminum

Figure A3-2: The central shaft and two aluminum support tubes of MGR are shown. At the base of the central shaft is copper commutator and just above this is one of the 6" driving gears. The timing belt is shown leading off to the other driving gear attached to the Boston Gear worm.

box (see Figure 3-3) which contains the electronics. The box is 22" long, 12" wide, 10" high, and is mounted 5" above the top plate. It is constructed out of .065" aluminum sheet riveted to an aluminum channel (1") frame. Styrofoam insulation (3/4" thick) is fitted inside the aluminum box, and inside of this is mounted a copper shield and heat sink.

One end of the box is cut out to allow the TED¹ (see Page A3-11) to butt against the copper shield.

Inside the box aluminum channels are mounted on rubber mounts. The electronics is mounted via another set of rubber mounted channels to the first set. This helps to reduce vibrations reaching the electronics, caused by the fans and motion of the MGR.

The fans are mounted on rubber shock mounts to the box. The purpose of the fans will be discussed later. Also mounted to the end of the box is the support housing for the precision regulators and the heat sink and regulators for the fans and temperature regulating equipment to be discussed later (see Figure 3-3).

The drive mechanism consists of a 1/2 HP motor, (see Figure 3-4) speed reducer clutch and timing belt and gears. The Boston Gear reducer is connected to the Tru Grip gear by a ratchet clutch. The function of the clutch is to allow the MGR to rotate freely when and if the motor was turned off. This is absolutely necessary since the

¹ Cambion Theroelectric Device.

Figure A3-3: The aluminum box mounted at one end of the MGR arm is shown with the copper screen shielding in place. On top of the box can be seen the circulating fan. Just below the box and mounted on the upper aluminum arm is a General Radio variable delay line. At the end of the box the precision regulators are just visible through the screen.

Figure A3-4: The drive mechanism is shown, the motor, gear reducer, driving gears and belt. Below the drive gear on the central shaft can be seen the two copper commutator rings.

MGR has a large angular momentum and if the input shaft of the gear reducer stops then the output of the reducer stops and cannot be turned. This would destroy the drive belt. The clutch consists of a bottom plate attached to the gear. The shaft from the reducer passes freely through the gear to the top plate of the clutch. Two cogs mounted on this plate mate with grooves cut in the bottom plate when rotating in one direction. The may be reversed so that the same action would take place if the motor was reversed.

The MGR rotates with a period of about 1.7 seconds. The boxes at the ends of the arms push a large amount of air against the walls of the concrete block room that contains the apparatus. Large vortices of air are created in the corners of the room causing the MGR to try to slow up as the arms entered the corners. This causes vibrations on the arms. This problem was solved by mounting a circular wall around the room concentric with the MGR. The least expensive material of the correct size is a swimming pool wall and hence the colourful pattern in the room (see Figure 3-2).

660H15

660H15

660H150

Four separate electrical systems are used to power the MGR apparatus. There is no common ground nor are there any direct electrical connections. This is done to ensure immunity from electrical coupling between the systems. Each of these systems is described in this section.

i) Motor Supply

A General Electric 115 Vac, 8.6 amp., .5 horse power continuous duty reversible motor was used to provide the rotational power for the MGR (see Figure 3-4). This motor is coupled to a reduction worm gear¹ (input RPM 1725, 570 inch pounds torque, ratio 50:1). The gear in turn is coupled to the main shaft of the MGR by a 1.5 inch Truegrip timing belt on two 6 inch diameter timing gears. The final period of rotation of the main shaft is about $1.7042 \pm .0008$ seconds. The effect of backlash and non uniform gear teeth is greatly reduced by the back pressure of the air against the moving MGR and the large number of teeth in contact with the driving belt.

The motor is controlled by a Square D motor controller type SB04 (Figure 3-5). This unit provides remote operation of the motor (on-off, reversing and safety switches). The relays in the controller (both forward and reverse) are powered via the Forward-Off-Reverse switch and a safety latching relay switch. This latter switch and closes only if the doors to the MGR room are closed or if manually

¹ Boston Gear Series 300

Figure A3-5: Motor controller, showing the forward relay above the reset switch, the reverse relay to the right and the variac.

overridden. If one of the doors is opened or the power is interrupted the latching relay prevents an uncontrolled start up. Once tripped the relay has to be manually reset. This is a necessary precaution since if 115 Vac is instantaneously applied to the field windings an unacceptable mechanical shock to the apparatus results. In order to obtain a smooth, controlled startup a variac is used to slowly bring the voltage up on the field coil. The wiring of this system is shown in Figure 3-6.

This motor-gear system provides a good rotational stability with a period of typically $1.7042 \pm .0008$ seconds over several hours. During a twenty four hour period the rotational period slowly changes by about four milliseconds.

ii) Large Current Supply

The electronics, as mentioned earlier, are housed in a temperature-controlled, copper-lined, insulated aluminum box. The temperature is maintained by a Cambion Thermoelectric Device (TED) model 3970 and a 2N3055 transistor used as a heater. These will be described shortly. To cool the TED and to circulate the air in the aluminum box two 12 VDC General Motors (CTC 303610) fan motors are used.

The above system is identical for both ends of the MGR. The power, 12 VDC at 10 amperes each, is supplied by a single Harrison Laboratories Inc. Model 814A regulated power supply (0-36 V, 0-25 amps). The power supply provides line and load regulation of better than .03% or 10mv (which

Figure: A3-6 Wiring for motor controller

ever is greater) and .05% or 12ma (whichever is greater). The noise and ripple is less than 1 mv rms and less than 10ma rms. The supply is operated in the floating mode, thus isolating the outputs from ground. This supply is also used to provide power from a third output, to the logic interface on the MGR. Signals to and from this interface are optically coupled thus keeping a high degree of noise immunity.

The power from the supply entered the MGR via a two-ring copper commutator located at the base of the MGR (see Figure 3-4). The commutator rings, mounted on the rotating shaft of the MGR are 5 inches OD, 4 inches ID and .5 inches high. Two 10 amp carbon brushes, at 90 degrees to each other, mounted on the MGR base provide contact on each ring. Brush noise is reduced by .1 uf capacitors across the rings. The brushes are cooled by two Boxer fans.

The fan motors mounted on the aluminum boxes generate a large amount of ripple, in excess of 1 v rms. They were expected to operate continuously for periods of many months. This was impossible since they wore their brushes out in about 60 days. Both problems were solved by reducing the brush pressure, filtering each motor and operating them at about 8 volts instead of 12.

Figure 3-7 shows the end of one of the aluminum boxes where the electronic power supplies, the top of the circulating fan and the power supplies for the TED, heater

and fans can be seen. Figure 3-8 shows the wiring schematic of power circuit for the MGR, while Figures 3-9 and 3-10 show the circuit diagrams for the power regulators regulators for the fans, heater and TED and the 5 volt 1 amp. regulator for the logic interface. Figure 3-10a shows the regulation characteristics of the 1 amp. regulator.

iii) Regulated Supplies

At each end of the arms of the MGR is an almost identical system of control electronics and oscillator. Each system has its own completely independent power system (although they are identical). Only one system will be described. Ten separate regulators are used on one system as can be seen in Figure 3-11. The power to these regulators was provided by three Lambda power supplies (2 model LCS-B-04 and 1 model LCS-4-04). The power supplies are further isolated from the AC line by the use of Hammond model 171F isolation transformers. The power from the Lambda supplies is brought onto the MGR through an Airflyte, 16-ring commutator (model CAY-125-16-3). The commutator is shown in Figure 3-12. This silver graphite commutator has very low D.C. resistance, only a few milliohms. At 24 volts and 1 amp. the D.C. level through two pairs of rings (onto and off the MGR) does not fluctuate by more

Figure A3-7: This photograph shows one end of an aluminum box where the power regulators and fans and TED are mounted.

Figure A3-8: Wiring of MGR commutator

Figure A3-9: Schematic wiring for fans

Figure A3-10: 5 volt 1 ampere regulator for the MGR interface.

Figure: A3-10a Regulation characteristics of positive 1 amp 5 volt regulator.

than 5 m/sec. The operating speed. The frequency properties of the commutator are shown in Figure 3-13. The commutator has a frequency cut-off of about 10^5 Hz, which is more than adequate for this experiment.

The oscillators require a long time (up to 24 hours) to reach a high degree of stability and therefore they are powered by Gel Cell rechargeable batteries. The batteries, manufactured by Globe Union, are under a constant slow charge (Figure 3-8). As shown in Figure 3-8 the power from the batteries to the oscillators uses the Airflyte commutator. This same figure shows the wiring schematic for the regulators and the commutator.

The ten regulators are constructed out of Fairchild 723 voltage regulators and appropriate transistors for the load requirement. The regulator functions are described in Table A3-1 while their circuits and characteristics are shown in Figures 3-14 to 3-31. Since the commutator increased the noise on the power lines the regulators were tested for output noise as a function of injected noise. Typical results are shown in Figure 3-32. As can be seen the regulators have good noise rejection.

Figure A3-11: The ten regulators for the precision electronics are shown mounted on the Aluminum box. Four large filter capacitors can be seen to the left on the photograph.

Figure A3-12: The Airflyte commutator is shown attached to an aluminum plate on which are also attached the small disc magnets which are used to determine the position of the MGR. On the left hand side of the photograph suspended by the central shaft are the two magnetic pick-up coils. Above these are situated the amplifiers and drivers for the coils.

Figure A3-13 Frequency Characteristics of Commutator.

Voltage (volts)	Current (milliamperes)	Function
24	220	oscillator heater
20	40	oscillator electronics
5	120	phase detector
15	50	DAC Supply
-15	50	DAC Supply
5	500	DAC Logic
24	200	Temperature Control and TAC
12	200	TAC Supply
-24	200	Temperature Control and TAC
-12	200	TAC Supply

Table A3-1: Regulator Functions

Load current (milliamps) at 33 volts

A3-25

Supply Voltage (volts) at 40 ma.

Figure: A3-15 Regulation Characteristics of positive 20 volt reference supply

Figure A3-16:
24 volt Regulator

Figure A3-17:
-24 Volt Regulator

Figure:A3-18 Regulation Characteristics of positive 24 volt regulator.

Figure A3-19 Regulation characteristics of negative 24 volt regulator.

Figure A3-20: 15 Volt Regulator

Figure A3-21: -15 Volt Regulator

Figure: A3-22 Regulation Characteristics of positive 15 volt regulator.

Figure:A3-23 Regulation Characteristics of negative 15 volt regulator.

Figure A3-24: 12 Volt Regulator

Figure A3-25: -12 Volt Regulator

Figure: A3-26 Regulation Characteristics of positive 12 volt regulator.

Figure: A3-27 . Regulation characteristics of negative 12 volt regulator.

Figure A3-29: 5 Volt Reference Regulator

Figure A3-29: 5 Volt Regulator

Figure: A3-30 Regulation Characteristics of positive 5 volt reference supply.

Figure: A3-31 Regulation Characteristics of positive 5 volt regulator.

Figure: A3-32 Regulator (typical) output ripple as a function of injected noise.

Apparatus: Electronics

As indicated earlier there were two different sets of equipment developed to perform the first order ether search. In this section both sets will be described in some detail. In either case the function of the equipment was to measure the relative transit time of signals along a path length and to determine any changes in this time due to an ether. In both sets of apparatus almost identical equipment was mounted in the aluminum boxes at each end of the MGR arm. (Each set was used separately).

Each box contains one Hewlett Packard model K07-105A 5MHz quartz crystal oscillator. The manufacturer's specifications are contained in Table A3-2. This oscillator requires a 24 Vdc, 220 ma, <1v ripple power supply for its oven and a 20 Vdc, 40 mv, <2mv ripple supply for the oscillator proper and the associated electronics. These are supplied by the precision regulators as described earlier, (see Figure 3-11). The oscillator's frequency may be changed by a coarse control mounted in the unit and a fine control which must be provided externally. This is described later. The stability of the oscillator is subject to variations in its power supply voltage, its fine frequency control voltage, temperature and vibration. Each of these effects were investigated.

In Figures 3-33 and 3-34, the change in period of the oscillators is shown as a function of supply voltage. As can be seen, a change of 1 mv in supply voltage causes

TABLE A3-2: Hewlett-Packard Component Oscillator
K07-105A Specifications.

Crystal:	Type: Hewlett-Packard 5 MHz, 5th overtone. Construction: High temperature backout, Coldweld.
Output Frequency:	5 MHz sinusoidal.
Output Voltage:	≥ 1 Vrms in 50 Ω ; DIV output 70 mV $\pm$ 10 mV into 1000 Ω .
Aging Rate:	$< 5 \times 10^{-10}$ per 24 hours.
Warm Up:	1×10^{-9} in less than 1/2 hour at 25°C. Reaches aging specification in less than 24 hours after 24 hour off time. (25°C Ambient)
Stability:	As a function of ambient temperature in still air: $< 2.5 \times 10^{-9}$ from 0°C to +50°C. As a function of load: $< \pm 2 \times 10^{-11}$ for any of the following loads: open, short, 50 Ω resistive, 50 Ω inductive, 50 Ω capacitive. As a function of supply voltage: $< \pm 5 \times 10^{-11}$ for 22-30 Vdc.

STANDARD DEVIATION OF 5 MHz OUTPUT*
(due to noise and frequency fluctuation):

Averaging Time	Fractional Frequency Deviation $\left\langle \sigma \frac{\Delta f}{f} (2, \tau) \right\rangle^*$	Phase Deviation (milliradians)
1 ms	8.0×10^{-10}	.026
10 ms	1.5×10^{-10}	.047
0.1 s	1.5×10^{-11}	.047
1 s	5.0×10^{-12}	0.16
10 s	5.0×10^{-12}	1.6

*Application Note 116 (HP Stock No. 5952-0512) describes
methods used to arrive at standard deviation specifications.

All data is based on at least $N = 50$ samples except $\tau = 10s$ where 10 samples are used to reduce crystal aging effects.

Data is corrected for zero dead time between measurements; measurement system bandwidth is 100 kHz.

Signal-to-Noise Ratio:	> 90 dB below rated output; (filter bandwidth, 3 dB = 100 Hz).
Harmonic Distortion:	Down more than 40 dB from rated output.
Non-Harmonic Components:	Down more than 80 dB from rated output
Output Terminals:	5 MHz(1V) and DIV (5 MHz at 70 mV); +15 reference for fine tuning.
Frequency Adjustments:	Coarse Adjustments: 1×10^{-6} coarse control is screwdriver adjustment. Fine Adjustments: external voltage to EFC connectors (+15V reference may be used).
Phase Locking Capacity:	An external +5V to -5V applied to EFC- connector allows > 2 parts in 10^8 frequency control for locking to an external source. EFC+ connector must be biased to approximately +6V.
Environmental:	Storage Temperature: -40°C to $+75^{\circ}\text{C}$ (-40°F to $+167^{\circ}\text{F}$) Operating Temperature: 0°C to 50°C ($+32^{\circ}\text{F}$ to $+122^{\circ}\text{F}$) Humidity: 0-95% Vibration: Mil-Std-167 Altitude: 50,000 ft. (15,2 km) Shock: 30 G's
Power Requirements:	115V $\pm$ 10% at 50W for 2 to 3 min. (optional for fast warm-up) 22 to 30 Vdc at 110 mA (220 mA warm-up) < 1V ripple. 18 to 20 Vdc at 40 mA < 2 mV ripple; < 20 mV regulation
Dimensions:	2.678" x 2.678" x 5.406" overall.
Net Weight:	17-1/2 ozs. (500 gms)

Figure: A3-33 Change in Beat Period as a function of oscillator A supply voltage.

Figure: A3-34 Change in Beat Period as a function of oscillator B supply voltage.

a change of about 2.5×10^{-7} ps in the period of the oscillator. Thus with the quality of regulation supplied to the oscillator there is no need to worry about the frequency stability due to power supply instabilities.

Figures 3-35 to 3-38 show the period of the oscillators as function of control voltage. A change of 1 mv in control voltage changes the period of the oscillator by 5.5×10^{-7} ps. This is a fractional change of 2 parts in 10^{12} . In order to maintain a high degree of stability the control voltage cannot be allowed to vary by much more than a few millivolts. This is usually achieved by the control voltage circuit to be described later. It is interesting to note that when the radio station was broadcasting, upwards of 50 to 100 mv rms (92 mHz) appeared on the control voltage line. This was partially rectified inside the oscillator causing noticeable changes in the period of the oscillator of up to 2×10^{-5} ps. or about 1 part in 10^{10} .

The oscillator and associated electronics are housed in a temperature controlled oven. In spite of this, changes in outside temperature do have some effect on the period of the oscillators as a function of temperature. A change 1°C causes a change of about 10^{-6} ps. or 5 parts in 10^{12} . Thus it can be seen that it is most important to have external temperature control in order to maintain good frequency stability.

Figure: A3-35 Change in Beat Period as a function of control voltage on Oscillator A (25 C.)

Figure: A3-36

Change in Beat Period as a function
of control voltage of oscillator A.

Figure:A3-37 Change in Beat Period as a function of control voltage of oscillator B.

Figure: A3-38 Change in Beat Period as a function of control voltage of oscillator B.

Figure: A3-39 - Change in Beat Period as a function of box temperatures.

The oscillators are very sensitive to accelerations. Unfortunately the oscillators behave differently when the two are compared to each other for the same applied acceleration. Figures 3-40 and 3-41 show the changes in period of the oscillators as a function of acceleration along two different axes of the crystals. It was initially hoped that both oscillators would behave similarly so that they could be so mounted as to compensate for the effects. Certainly if both oscillators frequencies drifted in the same direction by the same amount then the difference in their periods would remain constant and the change in the beat period would be small. However as can be seen from these graphs the oscillators were not identical and the effects had to be accepted.

The oscillators were subject to vibrations at start up, air currents set up by the motion of the MGR and imperfections in the main bearings. The first effect dies out rapidly but this is immaterial since data is not collected until 24 hours after start up to allow everything to reach equilibrium. The oscillators were also susceptible to induced voltages on the control voltage input due to the motion of the MGR through electric and magnetic fields set up by various electronic and metal pieces in the laboratory. Unfortunately it appeared that all of these last effects remained constant over long enough periods of time so that they could be treated as background and subtracted from the data.

Figure: A3-40

Change in Period of Oscillator A as a function of rotation about its x axis (due to acceleration of gravity).

Figure: A3-41 Change in Period of Oscillator B as a function of rotation about its x and y axes (due to acceleration of gravity).

The oscillator output (Figure 3-42) was reshaped into a series of narrow pulses by the circuit shown in Figure 3-43. In this circuit the output of the oscillator is fed into a step up transformer whose secondary fires a Flip-Flop. The Flip-Flop output is shaped to a 50 ns width by an RC circuit. Figure 3-26 shows the resonance curve of the two transformers used. The input impedance was $\sim 50\Omega$, 16 turns, #30 wire around type 4C4 Ferrobox toroid. The 50 turn secondary leads were attached to the inputs of a set reset Flip-Flop. The square waves produced, Q and $\bar{Q}$, were both further shaped into 50 ns wide pulses. This device was very stable and the +5 Vdc supply to it was very carefully filtered. The risetime of the pulse was about 1 V/ns and thus a 1 mv change in amplitude would cause a 1 ps change in time.

One of the oscillators was connected to a circuit designed to control its frequency. This circuit was necessary for both ether search techniques although of course no changes were made while data was being collected. The reason for the use of the circuit will be described later. Figure 3-45 shows the circuit diagram for the fine frequency control circuit. Figure 3-46 shows the output voltage of this circuit as a function of temperature of the aluminum box, and Figure 3-47 shows the output voltage of the DAC as a function of the above temperature. Figures 3-35 to 3-38 show the change in period as a function of the control voltage.

The output voltage of the DAC is controlled by an Analog Device 12-bit Digital-to-Analog converter. The out-

put is attenuated and added to a temperature stabilized zener diode voltage of 9.31920 volts (1N2624A - .0009%/°C). The output goes to the fine frequency control of the oscillator. Both the device and the oscillators are housed in individual copper boxes, which act as electric shields. Table A3-3 contains the DAC specifications. The DAC receives its information from a PDP9/L computer via the interface mounted on the MGR. This interface will be described later.

In both methods the signals whose transit times are being examined travel down a General Radio Transmission air line. As this line rotates around on the MGR the induced emf between the conductors (due to stray fields) never exceeds .1 mv. The total length of the line is 420 cm.

In the TAC (Time-to-Amplitude Converter) method, the oscillator pulses enter a logic circuit which is used to alternate the source of the stop pulse to the TAC. The logic circuit designed for this purpose is shown in Figure 3-48 and Figure 3-49.

In Figure 3-48, it can be seen that the oscillator Q signal is divided into two, one which goes through a gate to a line driver forming the start signal for the TAC. The other follows a similar path forming the stop signal. The start gate is controlled by the Q oscillator pulse and the veto on signal. This circuit ensures that the gate is open before the Q signal arrives. The stop gate is similarly controlled except it is further gated so that

5 MHz.

Flip Flop
output

(A)

5 MHz.
pulses (A_d)delayed
pulses

(see Fig. 3-26)

Figure :A3-42 Oscillator output and
shaped signals

Figure: A3-43 Oscillator pulse shaping circuit and beat detector.

Figure: A3-44 Resonance curves for the 5 MHz, transformers, for Oscillators A and B.

Figure A3-45 Fine voltage control circuit for oscillator A.

Figure: Oscillator Control Voltage as a function of temperature.

Figure: DAC voltage as a function of temperature.
A3-47

Table A3- ; Analogue Devices 12-Bit DAC
Specifications

ELECTRICAL

Input Number	Up to 12-bits TTL compatible
Input Levels	"0" <+.5V @ -3.2 ma., "1" >+2V @ 80 nsec. (with register). "0" <+.5V @ -2.5 ma., "1" >+2.6V @ 10 nsec. (w/o register).
Strobe	Same as above. Transition from "0" to "1" transfers data. Register is isolated at all other times. Note: Register will follow input with strobe at "1"
Input Codes	Binary, BCD
Output Ranges	0 to +2 V. 0 to +5V or -5V 0 to +10V or -10V ± 5 V. (except for BCD) ± 10 V. (except for BCD)
Output Current	± 10 ma.
Output Impedance	< .1 ohm (with amplifier options)
SPEED OF CONVERSION	
High-Speed Option	30 volts/usec. slew rate 2 usec. to settle to .1%
Medium Speed Option	1 v/usec. slew rate 20 usec. to settle to .1%
Linearity	1/2 LSB
Temperature Coefficient	.002%/°C
Operating Range	0 to +70°C
Power Supply	(see Pin Connections)

Figure: A3-48 TAC Logic control circuit.

Figure :A3-49 TAC method control logic
circuit board.

only every second Q pulse is allowed through.. This is to allow the TAC to be stopped by the Q pulse from the other oscillator. One cannot have both signals travelling at the same time in the transmission line since their combined signals decreased the resolution of the TAC's. This final circuit also included an input signal to ensure upon start-up that the flip flops were in the correct state. A tag signal was also produced in order to tell the TAC, ADC and interface that an event was to be processed.

The TAC's used were a matched pair of Ortec 457's and the ADC used was a Northern Scientific 622. The manufacturers specification are in Table A3-4. Originally the TAC outputs were brought out of the MGR by a LED-photomultiplier system but this did not prove very satisfactory so the ADC was then mounted on the MGR. The output of the TAC's were added together by a 50 Ω adder.

The beat method apparatus consists primarily of a J-K flip flop (74S112), the clock signal being provided by the $\bar{Q}$ signal of one oscillator and the J input provided by the Q signal of the other oscillator. The circuit and timing diagrams are shown in Figures-3-50, 3-42 and 3-43. A second J-K flip flop is used to clear the first flip flop. This second flip flop used the delay Q signal from the first oscillator for its clock input and the same Q for the J input as did the first. The output of the first flip flop (beat signal) was shaped to 50 ns wide and then through a

Table A3-4: ORTEC TAC Specifications

PERFORMANCE

Time Range: Switch-selectable 15-range choices of 0.05, 0.1, 0.2, 0.4, or 0.8 μsec multiplied by X1, X10, or X100.

Time Resolution: $<10 \text{ psec}$ (10^{-11} sec) FWHM on 50- and 100-nsec ranges; $<0.01\%$ FWHM of full range for all other ranges.

Temperature Stability: $<\pm 10 \text{ psec}/^{\circ}\text{C}$ for 50-nsec range;
 $<\pm 0.15\%/^{\circ}\text{C}$ for higher ranges.

Differential Nonlinearity: $<\pm 2\%$ from 5 nsec through full range for 50- and 100-nsec ranges;
 $<\pm 2\%$ from 5% range to full range for all higher ranges.

Integral Nonlinearity: $<\pm 0.1\%$ from 5 nsec through full range for 50-nsec ranges; $<\pm 0.1\%$ from 5% range to full range for all higher ranges.

Input Count Rate: 457 is dc-coupled and gated so that input count rate will not paralyze or hinder normal operation.

Fine Gain

Accuracy: $<\pm 5\%$ x coarse gain

Nonlinearity: $<0.5\%$

Resettability Error: $<0.1\%$

Bias

Accuracy: $<\pm 1\%$ internally adjustable

Nonlinearity: $<\pm 0.5\%$

Resettability Error: $<0.1\%$

Temperature Stability (for voltages $\text{ppm} = 10 \mu\text{V}/-10 \text{ V}$)

Gain: $<\pm 50 \text{ ppm}/^{\circ}\text{C}$

Bias Level: $<\pm 20 \text{ ppm}/^{\circ}\text{C}$

D.C. Level: $<\pm 10 \text{ ppm}/^{\circ}\text{C}$

Table A3-4: ORTEC TAC Specifications (continued)

CONTROLS

- Time Range: Front-panel 5-position selector switch; settings are 0.05, 0.1, 0.2, 0.4, and 0.8 μ sec.
- Multiplier: Front-panel 3-position selector switch; settings select multiplier factors for the selected Time Ranges of X1, X10, and X100, resulting in 15 time ranges from 50 nsec to 80 μ sec (other ranges available with minor modification; see Section 6.4).
- Delay: Front-panel single-turn screwdriver potentiometer adjusts the output delay from the Stop Input to the internal strobe; range <1 μ sec to >5 μ sec.
- Gate: Front-panel slide switch selects either Coincidence or Anticoincidence logic for gating the Start Input circuit.
- Strobe: Front-panel slide switch selects either Internal or External Strobe mode to determine the timing of the Pos and Neg analog outputs after Stop.
- DC Level: Front-panel 20-turn screwdriver potentiometer adjusts the dc baseline for the Pos and Neg analog outputs to ± 1 V.
- Coarse Gain: Front-panel 4-position selector switch; settings select a biased amplifier post gain factor of X1, X2, X5, or X10.
- Fine Gain: Front-panel calibrated 10-turn locking potentiometer for continuous adjustment of biased amplifier post gain factors from X0.5 through X1.5 times coarse gain.
- Bias Level: Front-panel calibrated 10-turn locking potentiometer for continuous adjustment of the bias level through the linear output range of 0 to 10 V.

OUTPUTS

POS

- Amplitude: 0 to +10 V linear; ± 12 V max; unipolar
- Rise Time: <300 nsec
- Width: Internally adjustable 1.0 to 2.5 μ sec
- Timing: Prompt at strobe time, either internal or external.
- Output Impedance: <1 Ω , dc-coupled
- Baseline Adjustment: ± 1 V dc with front-panel screwdriver control.
- Protection: 100% protected from shorts and excessive duty cycles.
- Connector: Front-panel type BNC.

Table A3-4: ORTEC TAC Specifications (continued)NEG

Amplitude: 0 to -10 V linear; - 12 V max; unipolar

✓ Rise Time: <300 nsec

Width: Internally adjustable -1.0 to 2.5 μ sec

Timing: Prompt at strobe time, either internal or external.

Output Impedance: <1 Ω , dc-coupled.

Baseline Adjustment: ± 1 V dc with front-panel ~~crew~~ driver control.

Protection: 100% protected from shorts and excessive duty cycles.

Connector: Front-panel type BNC.

ELECTRICAL

POWER REQUIRED

+24 V, 150 mA; -24 V, 155 mA;

+12 V, 90 mA; -12 V, 110 mA.

FROM ORTEC 457 MANUAL 1971

Figure:A3-50 Beat method circuit board.

line driver went to the scaling circuit.

The scaling circuit as shown in Figures 3-51 used the beat signals to open and close a gate to a scaler. This gate allowed through the Q signal from the first oscillator which was used as a time base. The 12 bit scaler output then went to the same interface as the ADC used.

The position of the MGR arm with respect to the laboratory was determined by the position of 16 circular ceramic magnets placed uniformly around the plate that the Airflyte commutator was mounted to. A seventeenth magnet was placed concentric with and just inside of the above ring of magnets. Mounted on a bar stationary with the laboratory were two pickup coils. These coils detected the passage of the magnetics. One coil was mounted concentric with and at the same radius as the ring of magnets while the second coil was aligned above the seventeen magnets. This last magnet determined the origin of the ring of magnets. The coil above the ring counted the number of magnets that passed since the origin thus indicating the position of the arm.

Figure 3-52 shows the circuit diagram of the pickup coils and amplifiers, while Figure 3-12 show the coils and ring of magnets. The signals from this circuit to to the external computer interface which will be described shortly.

Figure :A3-51 Beat Scaler Circuit

Apparatus: Interface

All data entering or leaving the MGR does so serially through two interfaces mounted on the MGR. One of the interfaces is primarily a parallel to serial converter which sends out either the ADC data or the beat scaler data. The other interface is a serial to parallel converter which receives the serial information from the computer and converts it for use by the DAC. The serialized data enters or leaves the MGR via the Airflyte commutator. The commutator at no time caused noise to be interpreted as data. This was checked by sending onto the MGR known data and receiving back the same and checking for changed bits.

Figure 3-53 shows the MGR Position Interface. The positive logic signals from the position detector (Figure 3-12) are inverted by an SN7400 gate and are scaled by SN7493 4 bit binary counter. The origin signal (Figure 3-53) (negative logic) is used to reset the scaler. The period of this signal was also measured and used to measure the speed of the MGR. The outputs of the counter go to a buffer which is strobed by the computer, thus loading the data into the computer. (The computer used in this experiment was a Digital Equipment PDP 9/L 18 bit 16K minicomputer). The positive logic signals also set a J-K flip flop thus ensuring a program interrupt flag request.

Figure 3-54 shows the parallel to serial converter on the computer. This sends data to the DAC. A series of

Figure :A3-52 Circuit of MGR position detector.

Figure: A3-53 MGR Position Interface

13, 200 ns wide clock pulses 10 ms apart are generated by the clock and its associated gating. The clock signal is split, one path being delayed with respect to the other path by 1.15 ms. The non delayed clock pulses are used to clock or strobe three, 5-bit shift registers (SN7496) in series with one another. They are loaded with data from a set of latches (8275) which in turn are loaded by the computer or from manual panel switches. The output of the final latch is added to the delayed clock producing the final serialized output.

The ADC - Beat interface on the MGR is almost identical except that there is no manual switch panel and the data is loaded by the ADC store signal or by the Beat store signal. This interface sends the data to the computer for analysis.

The serialized data is received by a serial to parallel converter. The data and clock signals are separated. The clock data being used to strobe the data into a set of shift registers and a set of latches to load to the computer gates (see Figure 3-55).

The serial to parallel converter on the MGR is almost identical to the above except that there is no final set of gates as these are part of the DAC circuit.

The beat period signals are also brought out through the Airflyte commutator. They are used to gate a 1 megacycle clock (Tektronix Type 184 time mark generator) which is counted on a TSI scaler (model 1535). This

Figure :A3-54 Parallel to Serial converter

Figure:A3-55 Serial to Parallel converter

information is used as a check on the data reaching the computer and as a measure of the overflow, the overflow being the number of clock pulses which overflowed the 12 bit beat scaler on the MGR. The overflow number was entered into the computer and added to the data, producing the beat period.

Apparatus: Temperature controllers

As mentioned earlier the electronics are housed in temperature controlled insulated boxes. The Cambion thermal electric device is used only for cooling, although it can be reversed.

The choice of TED depends upon the insulating properties of the box, the heat produced by the operating equipment, the desired operating temperature and the ambient environmental temperature of the box exterior. When the project began virtually none of the above parameters were known and thus the TED was chosen based on cost, weight, and an educated guess. The actual operating temperature had to be determined from the mean laboratory temperature, and the power dissipated by the electronics and leakage from the box.

To provide any extra necessary heating (if the laboratory temperature dropped) a 2N3055 transistor is used as a heater of up to 40 watts. Both the TED and the transistor are mounted on the inside copper lining of the box. This linear acts as a heat sink dissipating the heat. The inside cooling fan, see Figure 3-3, blows air onto the end of the copper box where the TED and 2N3055 are attached. The fan is necessary to circulate the air about the electronics which otherwise develop hot spots where the temperatures exceed desired operating conditions.

The power to the TED and 2N3055 is controlled by a 741 amplifier used in a bridge circuit containing a 10 k

(nominal) thermistor. The temperature characteristics of the thermistors used are shown in Figure 3-56. The gain of the amplifier determines the rate of change of the output for a change of temperature. Thus it is possible to control the temperature in the box by choosing an appropriate balancing resistor in the bridge and the response time of the TED - transistor by changing the amplifier gain. This is necessary in part so that a small change in temperature does not instantaneously cause the TED or transistor to be rapidly turned on or off, since the current surge causes electrical noise in the electronics. The fact that the thermistor temperature has to change by a degree or so before the TED or transistor reaches maximum capability is no problem since the electronics are further housed in small copper boxes and the inertia to temperature change is such that temperature of the electronics is almost always kept to within $\pm .1^{\circ}\text{F}$.

Figure 3-57 shows the circuit diagram of the temperature controller, while Figure 3-58 show the circuit diagrams of the TED cooler and transistor heater. Figure 3-59 shows the type of graph obtained by measuring the box temperature as a function of laboratory temperature and the corresponding temperatures in the electronics and TED plate temperature. From this graph the operating temperature of boxes was determined. The mean laboratory temperature was determined and found to be 70°F which corresponded to a electronic source temperature of 90°F . By using a box temperature of 70° , the cooler and heater combination could

maintain this temperature as the laboratory fluctuated between 65°F and 77°F.

Silica gel was placed inside the copper boxes in an attempt to keep the humidity in the boxes more or less constant, at about 50%. The humidity in the laboratory varied throughout the year from 20% to 80%. The variation in the boxes went from 30% to 60%.

The temperature of the laboratory is recorded at 6 different locations using a Honeywell 24 channel temperature recorder. This is done to determine if any major changes in laboratory temperature have any effects on the final data. Only when the laboratory temperature exceeds 75°F is there any sign of the data drifting. Above 80°F (air conditioner inoperative) no data was collected and usually the computer has to be shut down.

Figure: Thermistor Resistance as a function
A3-56 of temperature.

3 3

OF/DE

Figure :A3-57 Temperature controller

Cooling circuit

Heater circuit

Figure:A3-58 Cooling and Heating circuits.

Figure: Box temperature as a function of room temperature and load (heat source) temperature for various temperature regulator set temperatures.

A3-59

END

5 08 78

FIN