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The Accuracy of Modified Gunter's Quadrant (Ver.2) in Prayer Time Calculation

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Abstract
Gunter's Quadrant is the work of Edmund Gunter in modifying the Horary Quadrant but cannot be used to accommodate the needs of Muslims in knowing prayer times. In previous research, the author has developed the Modified Gunter's Quadrant (ver.1) which can be used for calculating prayer times and has succeeded in improving the basic design of Gunter's Quadrant so that it can be made for latitudes near the equator. However, the Modified Gunter's Quadrant (ver.1) produces curves that look broken and the accuracy of the calculation results still needs to be improved because the hour curves interval is 15 minutes. The method of research used is Development Research which becomes a further development of the Modified Gunter's Quadrant (ver.1) to eliminate deficiencies in the projection concept of the hour and azimuth curves and to improve the accuracy of the calculation results of prayer times. The result of this research is the Modified Gunter's Quadrant (ver.2) which has a better curve projection method and improved accuracy with hour curve intervals of 5 minutes. The results of the accuracy test show that the Modified Gunter's Quadrant (ver.2) deserves to be used as one of the classical instruments for calculating prayer times with a maximum error of $0^h\ 0^m\ 53^s$.
Keywords: Modified Gunter's Quadrant, Prayer Times, Calculation, Accuracy.

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INTRODUCTION

Gunter's Quadrant is a development of the Horary Quadrant made by Edmund Gunter in 1623. The modifications made by Gunter produce a new type of Horary Quadrant that has more functions than the previous model of Horary Quadrant. Gunter's Quadrant can not only determine the time based on the altitude of the Sun but also can determine the ephemeris data of the Sun and the position of the Sun at any hour in a location. These are functions that have not been found in previous types of Horary Quadrants.

The emergence of the Horary Quadrant is closely related to the needs of people at that time who began to realize the urgency of time in their daily lives. The sun which has a regular movement inspires people to make it a time marker. Then came an instrument that was made to help humans in determining time using the Sun's position. One instrument designed for this need is the Horary Quadrant. Horary Quadrant models and designs are constantly evolving according to human needs. One of those who developed it was Edmund Gunter, an English priest, mathematician, geometry, and astronomer of Welsh descent. The development carried out by Gunter is in the form of adding azimuth lines and modifications to the basic design of the Horary Quadrant. So that the sun's Ephemeris data can be calculated with his quadrant instrument, which is then referred to as Gunter's Quadrant.

Gunter's Quadrant is called a unique modification Horary Quadrant that was designed by Muslim astronomers. However, Gunter's Quadrant has the disadvantage of not having the scale or curves of the Sun's altitude below the horizon that can be used to calculate several prayer times. Gunter's Quadrant also still uses solar time and does not have the equation of time scale that can be used to convert solar time into mean time. In addition, the concept of Gunter's

Quadrant construction cannot be used to draw the projection of hour and azimuth curves for latitudes below 23°. These three shortcomings make Gunter's Quadrant difficult to use in time calculation nowadays. It is necessary to modify Gunter's quadrant so that it can be used in prayer times calculation.

In previous research, the author has modified Gunter's Quadrant as the result of his Master Thesis at UIN Walisongo Semarang. The results of the author's Master Thesis entitled *Gunter's Quadrant as an Instrument for Reckoning Prayer Times* is a Modified Gunter's Quadrant that can be used in prayer times calculation with an accuracy of 4 minutes. This level of accuracy can still be improved. In addition, the modified Gunter's Quadrant design still requires conceptual improvements in drawing projections of hours and azimuth curves. So in this paper, the author decide to make advanced modifications to Gunter's Quadrant (ver.2) to produce a better and more accurate Modified Gunter's Quadrant (ver.2) instrument.

RESEARCH METHOD

This research uses the Development Research method. In this research, the author develops a modified Gunter's Quadrant (Ver.1) from previous research so that it can be used for prayer times calculation with a better level of accuracy. The primary data sources used are a book by Edmund Gunter which contains a description of the construction and use of Gunter's Quadrant, the Master Thesis of the previous author's research on Gunter's Quadrant Modification as an instrument of reckoning prayer times, as well as books on astronomical calculations and celestial coordinates that will be used as the basis for making hour curves on Modified Gunter's Quadrant (Ver.2). On this research, the author uses descriptive analysis methods to describe the construction and application of Gunter's Quadrant which was then developed according to the needs analysis for the prayer times calculation. The author also uses a comparative method to get the accuracy of prayer times calculation using Modified Gunter's Quadrant (Ver.2). The development procedures that the author uses are as follows:

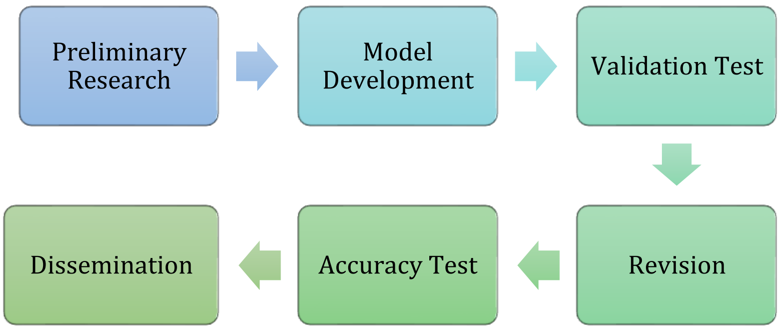

Figure 1. Development Procedures Used in the Research

1. Preliminary research. At this stage, the author collects literature on the design of Gunter's Quadrant and its application in determining time based on the position of the Sun. In addition, the author also collects literature on stereographic projection models and astronomical algorithms related to coordinate transformations. Then examine the shortcomings of Gunter's Quadrant and the previous Modified Gunter's Quadrant (ver.1) in their application to the needs of prayer times calculation in their design for the locations near the equator.
2. Model development. At this stage, the author draws a modified model of the curves on Gunter's Quadrant and adds several new scales and curves for the need for prayer times calculation. The design, projection, and modification made are based on calculation results of longitude, declination, altitude, and the azimuth of the sun in one year with a latitude of 7°

25' S. The design of Modified Gunter’s Quadrant (ver.2) is made using Corel Draw X7 and Oberon Plotter.

3. Validation test. At this stage, the author does a validation test to know the functionality of the Modified Gunter’s Quadrant (ver.2). To carry out the validation test, the author practice how to calculate prayer times using a modified Gunter's Quadrant (ver.2) and ensure that all instrument components are complete.
4. Revision. The revision stage is carried out if an error is found in the results shown by Gunter's Quadrant in the validation test.
5. Accuracy test. At this stage, the author conveys the development results of the Modified Gunter's Quadrant (ver.2) to astronomers and *ilmu Falak* activists, one of the chosen ways is through the publication of this article.

RESULTS OF RESEARCH AND DISCUSSION

Opinions of Ulama>’ on the Use of Instruments in Determining Prayer Times

The method of determining Muslim prayer times is not explained in detail in the Qur'an, but the prayer cannot be done at any time. This is following the word of God in al-Nisa '(4) verse 103:

فَأَقِيمُوا۟ ٱلصَّلَوٰةَ ۚ إِنَّ ٱلصَّلَوٰةَ كَانَتْ عَلَى ٱلْمُؤْمِنِينَ كِتَـٰبًا مَّوْقُوتًا

“Establish regular prayers! Indeed, performing prayers is a duty on the believers at the appointed times”.

The verse explains that there is a recommendation to perform prayers according to their time. This means that it is not permissible to delay performing the prayer because the times have been determined. Prayer has a time in the sense that there is a time when one has to complete it. When that time passes, then it means the prayer time also passes. Some words of that verse also indicate the meaning of a continuous and unchanging obligation, so that in the word of *mauqu>tan* it means that prayer is an obligation that does not change, must always be carried out, and never fail for any reason. According to Imam al-Shafi'i, the phrase *kita>ban mauqu>tan* means an obligation that cannot be postponed when the time for prayer has come.

The method of determining the beginning of Muslim prayer time can be divided into two, namely: the calculation method *(hisa>b)* and the Observation method *(ru’yah)*. The calculation method means calculating the beginning of prayer times by using astronomical formulas for the movement of the Sun to get the time at which the Sun is positioned as described in the Prophet's hadiths regarding prayer times. In the book *Kifa>yah al-Akhya>r* it is stated that knowing the time of prayer is one of the conditions for the validity of prayer *(syart} s}ih}ah al-S}alah)*. The use of the calculation method in determining the beginning of prayer time is allowed on the condition that the results of the calculation may only be used for those who do the calculation and not for others.

While the Observation method *(ru’yah)* in determining the beginning of prayer times is to see directly the signs of nature as mentioned textually in the traditions of the prophet. Not infrequently users of the *ru’yah* method in determining the beginning of prayer times use instruments to assist in observing the position of the Sun at the time of prayer. Classical instruments that are commonly used are sundial, *bencet,* or *gnomon (istiwa’* stick). The use of astronomical instruments as a tool in observing natural signs at the beginning of prayer times is allowed because there is a hadith text that mentions the beginning of the Asar prayer time not based on the position of the Sun but on the length of the shadow:

حدثنا مسدد حدثنا يحيى عن سفيان حدثني عبد الرحمن بن فلان بن أبي ربيعة عن حكيم بن حكيم عن نافع بن جبير بن مطعم عن ابن عباس قال: قال رسول الله صلى الله عليه وسلم أمني جبريل عليه السلام عند البيت مرتين ...... وصلى بي العصر حين كان ظله مثله .

"Musaddad has told us, Yahya> has told us, from Sufya>n, Abd al-Rahma>n bin Fula>n bin Abi> Rabi>'ah has told me, from Na>fi' bin Jubair bin Mut'im , from Ibn Abba>s, he said: Rasu>lulla>h saw. Has said: "Jibri>l led the prayer with me at home twice... Jibri>l did the Asr prayer with me when the shadow of the object was as long as the object…"

In this case, the use of the astronomical instrument is very necessary. To get the exact time of Asar prayer, the object that is seen by the shadow must be an object that is upright on a straight plane. Otherwise, there will be an error in observing Asar prayer time. Thus, the use of this instrument is a *wasi>lah* (intermediary) for determining the exact beginning of prayer times because without these tools it can cause errors in determining the beginning of prayer times. In one of the *Qawa>'id us}ul al-Fiqh* it is stated:

ما لا يتمّ الواجب إلّا به فهو واجب

"As long as an obligation will not be perfect unless there is something, then something (intermediary) is legally obligatory"

Intellectual Biography of Edmund Gunter

Edmund Gunter was an English clergyman, expert Welsh mathematician, geometer, and astronomer. Gunter is very remembered for his mathematical contributions such as the inventions of Gunter's Chain, Gunter's Quadrant, and Gunter's Scale. Gunter was born in Hertfordshire in 1581. He was educated at Westminster School, and in 1599 AD he was accepted as a student at Christ Churches, Oxford. During his studies at Oxford, his interest in mathematics developed. He is interested in research on sundial models (Sundial), then he began to compose his mathematical instrument. He earned his BA on 12 December 1603 and MA on July 2, 1606. In March 1619, he became a professor of astronomy at Gresham College, London, and maintained this position until his sudden death at age forty-five.

Gunter's contributions to science were essentially practical. As a competent mathematician, he has a knack for designing instruments that simplify calculations in astronomy, navigation, and surveying. Gunter has an important role in the British tradition which puts navigation theory into instrument models that are suitable and easy to use at sea. Gunter's published works are written in a language that simple and applies mathematical theories to daily needs. Gunter's various instruments have a function that is important in its time and lasts a long time. The following are the works of Edmund Gunter:

1. *Canon Triangulorum.*

   Gunter's first mathematical work published in 1620 was the *Canon Triangulorum*, a book containing tables of the logarithms of the sine and tangent for each angle with an accuracy of 1 arc minute.

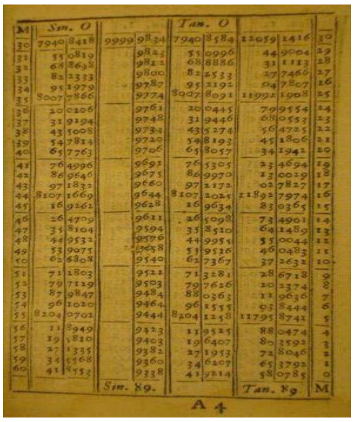

Figure 2. Table of Logarithms of Sine and Tangent in the Book *Triangulorum Canon*

2. *The Description and Use of Sector, the Cross-Staff, and Other Instruments for such as are Studious of Mathematical Practise.*

   In 1623 Gunter published the book *The Description and Use of Sector, the Cross-Staff, and Other Instruments for such as are Studious of Mathematical Practices* which describes a collection of mathematical works, their uses, and how to use them. In that book, Gunter also wrote about how to make each of his instruments. Unlike previous books, this book was written, and published, in English instead of Latin. Some of Gunter's instruments described in this book are:

   a. Gunter's Sector

      The sector is a mathematical instrument consisting of two hinged rulers that have an engraved scale. The scale of the two rulers makes it possible to solve various problems in trigonometry because the Sector instrument has two equilateral triangles in a constant ratio.

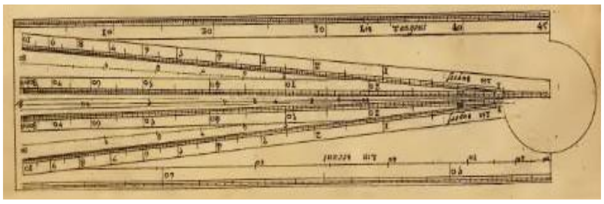

Figure 3. Gunter's Sector

Gunter was not the inventor of the Sector instrument. But he designed the Sector instrument with a new model and scale. The interesting fact about Gunter's Sector is that his Sector instrument was the first mathematical instrument written on a logarithmic scale to make solving numerical problems easier.

   b. Gunter's Cross Staff

      The Cross Staff was an instrument often used by British sailors and widely used by ancient astronomers for observing the altitudes and angular distances of celestial bodies. Cross Staff can also be used to measure the heights of objects on Earth and distances on land and sea.

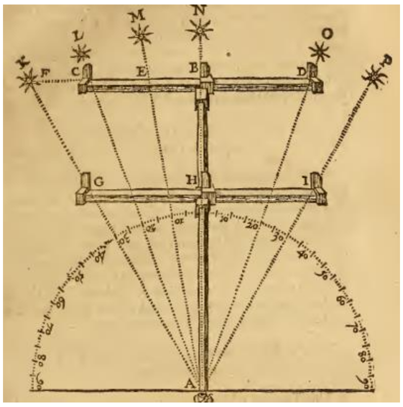

Figure 4. Gunter's Cross Staff

Gunter modified the existing Cross Staff model to make it easier to use in measuring distances and altitudes. The modification he made was in the form of adding lines and scales to the Cross Staff in Yard units. Gunter said that the modified Cross Staff will use a slightly different method of use but can also be applied in the same way and method as the old Cross Staff.

c. Gunter's Quadrant

Gunter's Quadrant is a pocket-sized instrument that is the result of Gunter's modification of the Horary Quadrant instrument model that existed at that time. Like other types of Horary Quadrants, the main function of Gunter's Quadrant is to determine the time of day by aiming for the Sun's altitude. When sunlight passes through the two eyelets on the top edge of the instrument, a thread with a weight at the end will indicate the Sun's altitude then the intersection between the thread and the hour curve will show the current time. If Gunter's Quadrant is used along with ephemeris data of celestial bodies, sailors or surveyors can aim it at the sun, moon, or stars to calculate the time of day or night, date, length of the day, time of sun's culmination, time of sunrise and sunset. Gunter's Quadrant is a portable instrument. However, because the scales and lines are only applied to one particular latitude, this instrument is often used on land.

Gunter's Quadrant Modification

The author attempts to modify Gunter's Quadrant so that Edmund Gunter's instrument can function properly and reduce the complexity of hour and azimuth curves for places with small latitudes. In making a new design for Gunter's Quadrant, the author used latitude 7° S as a reference for making the hour and the azimuth curves. Some modifications to Gunter's Quadrant design that the author did are as follows:

1. Modified Gunter's Quadrant (ver.1)

The Modified Gunter's Quadrant (ver.1) is the result of research conducted by researchers in 2019 to modify Gunter's Quadrant so that it can be used in the early reckoning of prayer times by improving the method of making each part and adding the equation of time scale. Some of the modifications made to Gunter's Quadrant design so that it becomes a modified Gunter's Quadrant (ver.1) are as follows:

a. Modification of the method in making ecliptic arc and declination scale

The ecliptic arc in Gunter's Quadrant basic design is only 90° of the ecliptic circle. The author considers that as the initial cause of difficulties in determining the position of the Sun. So the author tried to re-project the ecliptic circle on Gunter's Quadrant and projected 180° the ecliptic arc. The consequence of the 180° ecliptic arc projection model has modified Gunter's Quadrant which has two tropical circular arcs as the result of projection for the tropical circle of Cancer and the tropical circle of Capricorn. Thus, the declination scale in Gunter's Quadrant also has two, namely the declination scale which is calculated from the celestial equatorial arc to the tropical arc of Cancer for positive (north) declination. While the declination scale from the celestial equatorial arc to the Capricorn tropical arc for negative (south) declination.

The projection of 180° for the ecliptic arc is not a new model because several other quadrant-shaped astronomical instruments use this projection model, such as the *Novus* Quadrant and the Astrolabe. But in this modification of Gunter's Quadrant, the making of the Sun's longitude scale and the starting point of the zodiac uses the method formulated by Edmund Gunter, which is using the reference value of the Sun's right ascension. So the sun's longitude scale is determined by the value of the sun's right ascension calculated from Gunter's Quadrant arc. The position of each sun's longitude value from the beginning of the Gunter's Quadrant arc is based on the sun's right ascension value which is calculated by the following formula:

$\tan\alpha = \cos\varepsilon \ / \ \tan\lambda$ ....(1)

α : sun's right ascension

ε : true obliquity
λ : sun's longitude
The obliquity value or the ecliptic inclination from the celestial equator that is used by Gunter is 23°30'. Meanwhile, what the author uses is based on the Jean Meeus formula to calculate the average obliquity by the following formula:
U = T / 100

$$\varepsilon = 23^{o}\ 26'\ 21{,}448'' - 4680{,}93 * U - 1{,}55 * U^{2} + 1999{,}25 * U^{3} - 51{,}38 * U^{4} - 249{,}67 * U^{5} - 39{,}05 * U^{6} + 7{,}12 * U^{7} + 27{,}87 * U^{8} + 5{,}79 * U^{9} + 2{,}45 * U^{10} \quad (2)$$

T: century calculated from January 1, 2000

Using the formula above, the average obliquity value at the beginning of 2019 is 23° 26' 12". Based on this value, the sun's right ascension value of each zodiac that the author uses will be different from that used by Gunter. The following is a table of solar ascension values for each zodiac in the modified Gunter's Quadrant (ver.1):

Table 1. The Value of the Sun's Right Ascension for Each Zodiac

No	Zodiac	Sun's Longitude	Sun's Right Ascension
0	Aries	0°	0°0'0"
1	Taurus	30°	27°54'40"
2	Gemini	60°	57°49'10"
3	Cancer	90°	90°0'0"
4	Leo	120°	122°10'50"
5	Virgo	150°	152°5'20"
6	Libra	180°	180°0'0"
7	Scorpio	210°	207°54'40"
8	Sagitarius	240°	237°49'10"
9	Capricorn	270°	270°0'0"
10	Aquarius	300°	302°10'50"
11	Pisces	330°	332°5'20"

Based on the table above and the projection of the ecliptic arc that the author use, the initial position of the zodiac in Modified Gunter's Quadrant (Ver.1) is as follows:

Table 2. Zodiac Placement and Division on The Ecliptic Arc

Sequence Point	Zodiak	Arc angle on Gunter's Quadrant	Zodiac placement
1	Aries	0°0'0"	Above the arc of the equator
2	Taurus and Virgo	27°54'40"	
3	Gemini and Leo	57°49'10"	
4	Cancer	90°0'0"	
1	Libra	0°0'0"	Below the arc of the equator
2	Scorpio and Pisces	27°54'40"	
3	Sagitarius and Aquarius	57°49'10"	
4	Capricorn	90°0'0"	

b. Modification of calendar scale

The calendar scale that the author makes for Modified Gunter's Quadrant (Ver.1) is no longer based on the altitude of the Sun's culmination each day but it is based on the value of the Sun's right ascension each day. The following is a table of the average sun's right ascension at the beginning of each month:

Table 3. The Beginning of Each Month on the Gunter's Quadrant Calendar Scale

No	Month	Sun's Longitude	Sun's Right Ascension
1	January	281°	281°57'42''
2	February	313°	314°57'48''
3	March	341°	342°28'3''
4	April	12°	10°34'25''
5	May	41°	38°34'30''
6	June	71°	69°25'46''
7	July	100°	100°20'11''
8	Augustus	129°	131°25'53''
9	September	159°	160°35'53''
10	October	188°	187°20'51''
11	November	219°	216°36'42''
12	December	249°	247°17'48''

On the Modified of Gunter's Quadrant (Ver.1), the position of the calendar scale is in two places, both are above and below the equatorial arc. The calendar scale that is above the equatorial arc is occupied by the dates when the value of the sun's longitude is between 0° – 180° and the value of the sun's declination is positive (north). While the calendar scale under the equatorial arc is for dates when the value of the sun's longitude is between 180° – 360° and the value of the sun's declination is negative (south).

c. Modification of method in making the hour and azimuth curves

The author modifies the hour and azimuth curves projection method in Gunter's Quadrant by placing all of the hour and sun's azimuth curve when the Sun's declination is positive (north), above the equatorial arc. Then all of the hour and sun's azimuth curves when the Sun's declination is negative (south), and is placed above the equatorial arc. The separation of two types of curves on Modified Gunter's Quadrant (ver.1) is a consequence of making two kinds of tropical arcs, both are the tropical arcs of Cancer and Capricorn. In addition, separating the two types of curves based on positive and negative values of the sun's declination will reduce the complexity of curves on Modified Gunter's Quadrant (ver.1).

The author still uses the same method of making the hour curves as what was made by Gunter, it is by plotting the intersection between the sun's declination and the sun's altitude at each hour. Then connect the dots to make it an hour curve. The formula for calculating the sun's altitude used is:

$\text{Sin } h = \sin \varphi * \sin \delta + \cos \varphi * \cos \delta * \cos t$…………………(3)

h: sun's altitude
φ: latitude
δ: sun's declination
t: sun's hour angle

As for the making of the Sun's azimuth curve on Modified Gunter's Quadrant (ver.1), the author still uses the same method as what was used by Gunter, it is by plotting the intersection between the sun's declination and the zenith distance of the Sun at each azimuth. So that in making the Sun's azimuth curve, data on the zenith distance of each azimuth in one year is needed. The formula for calculating the zenith distance in each direction of the Sun is as follows:

$\text{Cotan } \gamma = \sin \varphi * \tan A_0$ ……………………………………………………………………(4)

$\text{Cos } \theta = \tan \delta * \cos \gamma / \tan \varphi$ ……………………………………………………………(5)

$HA = \theta + \gamma$ ....(6)
$Cos\ Zm = \sin \varphi * \sin \delta + \cos \varphi * \cos \delta * \cos HA$ ....(7)

γ : auxiliary angle 1
θ : auxiliary angle 2
HA : sun's hour angle
A_o : sun's direction
Zm : sun's zenith distance

The formula for calculating the sun's hour angle above is commonly used to calculate the sun's hour angle during *Ras}d al-Qiblah*. The reason the author uses this formula is because of the similarity of the formula analogy for calculating the sun's hour angle at *Ras}d al-Qiblah* with that required in making the azimuth curve, namely calculating the value of the sun's hour angle without knowing the value of sun's altitude and only using the available data, such as sun's direction, latitude and sun's declination.

The modifications that have been done to the method of making the ecliptic curve, calendar scale, hour, and azimuth curves, result in the Modified Gunter's Quadrant (ver.1) as follows:

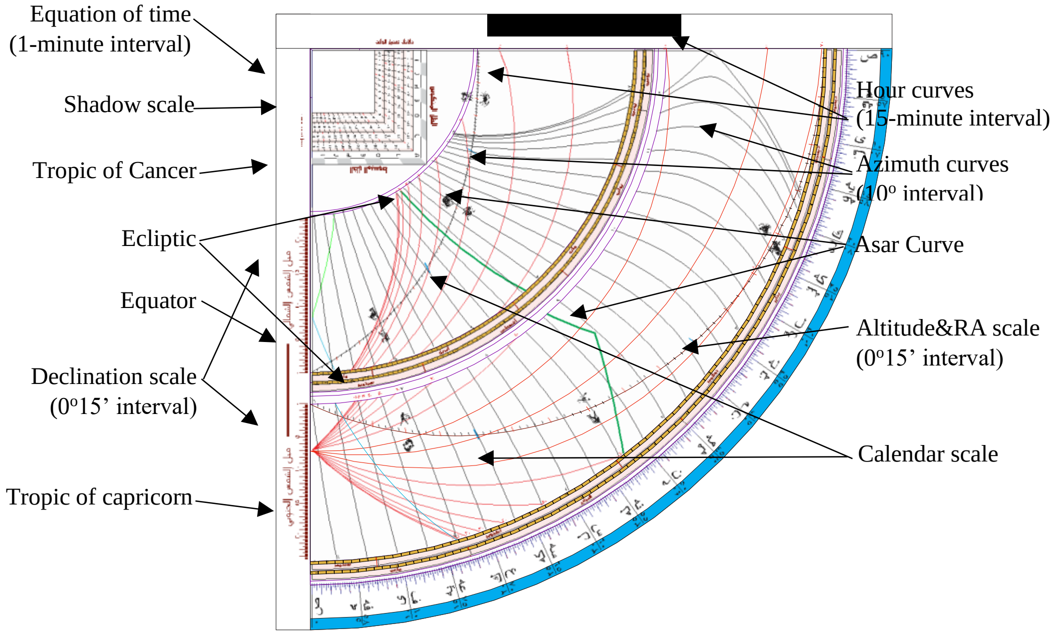

Figure 5. Modified Gunter's Quadrant (ver.1)

2. Modified Gunter's Quadrant (ver.2)

The Modified Gunter's Quadrant (ver.1) still needs design improvement. This can be seen from the hour and azimuth curves which look truncated due to the space between the positive and negative sun's declination scales. In addition, the hour curves on the Modified Gunter's Quadrant (ver.1) are made every 15 minutes. So the results of the calculation that was obtained, are still less accurate. Especially if it is used for the calculation of prayer times that require accurate results. Then the author developed Gunter's Quadrant (ver.1) design again to get a more accurate prayer time calculation result. The result of the development of Modified Gunter's Quadrant (ver.1) is called the Modified Gunter's Quadrant (ver.2). The developments carried out are as follows:

a. Connecting the hour and azimuth curves for the northern and southern declinations

On the modified Gunter's Quadrant (v.1), there is a calendar scale that separates the hour curve for the north declination from the hour curve for the south declination. This model is designed to distinguish the months when the sun's declination is positive from negative. however, it detracts from the beauty of the clock curve and azimuth display and causes the curves to appear cut off. So in the next development, this model needs to be improved.

In the second modification, the author relates the hour and azimuth curves at the northern and southern declinations. The dividing line between these two types of curves is only the arc of the celestial equator. So that the appearance of the fault curve will disappear. While all calendar scales are placed under the curve space. This causes the calendar scale to stack into four layers. However, users of the Modified Gunter's Quadrant (ver.2) can still easily distinguish the months when the Sun is north and south. The first and second layers of the calendar scale are the date and month of the northern sun's declination. While the third and fourth layers become the place for the date and month at the southern sun's declination.

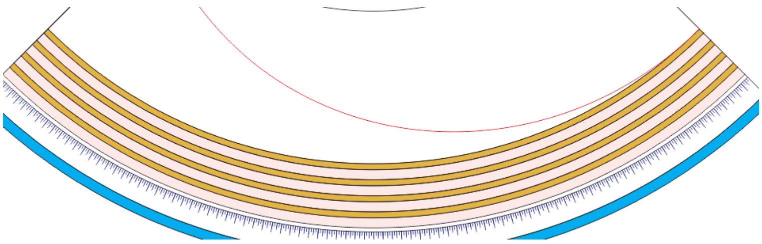

Figure 6. The Four Layers of Calendar Scale Layout on Modified Gunter's Quadrant (Ver.2)

b. Making hour curves every 5 minutes

On the Modified Gunter's Quadrant (ver.1), hour curves are created at 15-minute intervals. This is due to the limitations of the methods that the author could use in previous research. In the development of Modified Gunter's Quadrant (ver.2), the author plan to increase the accuracy of the instrument by making hour curves with 5-minute intervals. To make it easier to make hour curves with 5-minute intervals, the author uses additional software, namely Oberon Plotter as a Corel Draw add-on.

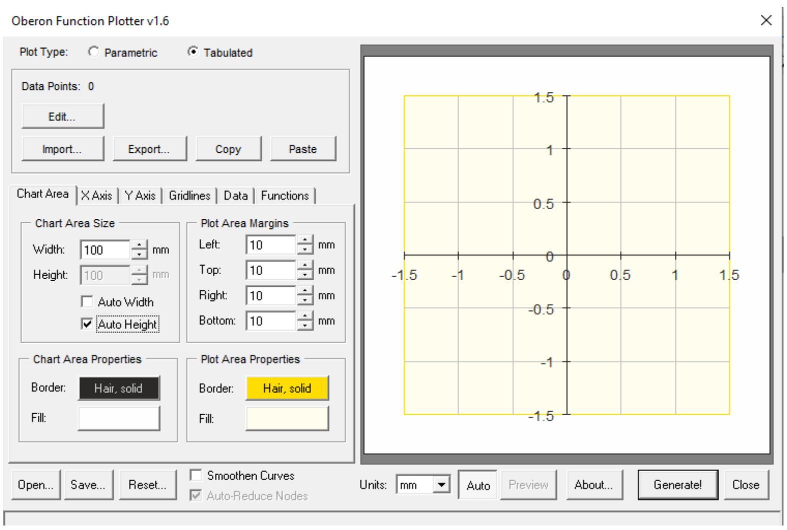

Figure 7. Oberon Plotter v.16 Interface

In making the hour curves in this second modification, the author uses the same method as the method used in the previous research. However, because using the Oberon Plotter, the author must define the intersection point between the sun's altitude and the sun's declination at each hour using the x-y plot model. The formula used is as follows:

$$x = \sin h * y \quad \text{.........} (8)$$

x = intersection point between the sun's altitude and the sun's declination at each hour
y = The length of the declination scale that is calculated from the Tropical arc of Cancer to the point of each declination value
h = sun's altitude

c. The Addition of the equation of time scale in 2022

The addition of the equation of time scale on Modified Gunter's Quadrant will make this instrument capable of converting the solar time indicated by the hour curves into mean time without having to use the equation of time tables from astronomy books or software. The addition of the equation of time scale on Gunter's Quadrant is by using the equation of time scale model which is placed above the shadow scales. On Modified Gunter's Quadrant (ver.1), the author has added the equation of time scale using Ephemeris data in 2019. Then on Modified Gunter's Quadrant (ver.2), the author renews the equation of time scale using Ephemeris data in 2022. The formula used to calculate the equation of time is as follows:

$$L_o = 280{,}4664567 + 360007{,}6982779 * T - 0{,}03032028 * T + T^3 / 49931 \quad \text{.........} (9)$$

$$e = Lo - 0{,}0057183 - \alpha + \Delta\psi * \cos \varepsilon \quad \text{.........} (10)$$

L_o = Sun's mean longitude
T = centuries calculated from January 1, 2000
e = equation of time
α = sun's right ascension
Δψ = correction of nutation in longitude
ε = true obliquity

The result of the second modification is the Modified Gunter's Quadrant (ver.2) as follows:

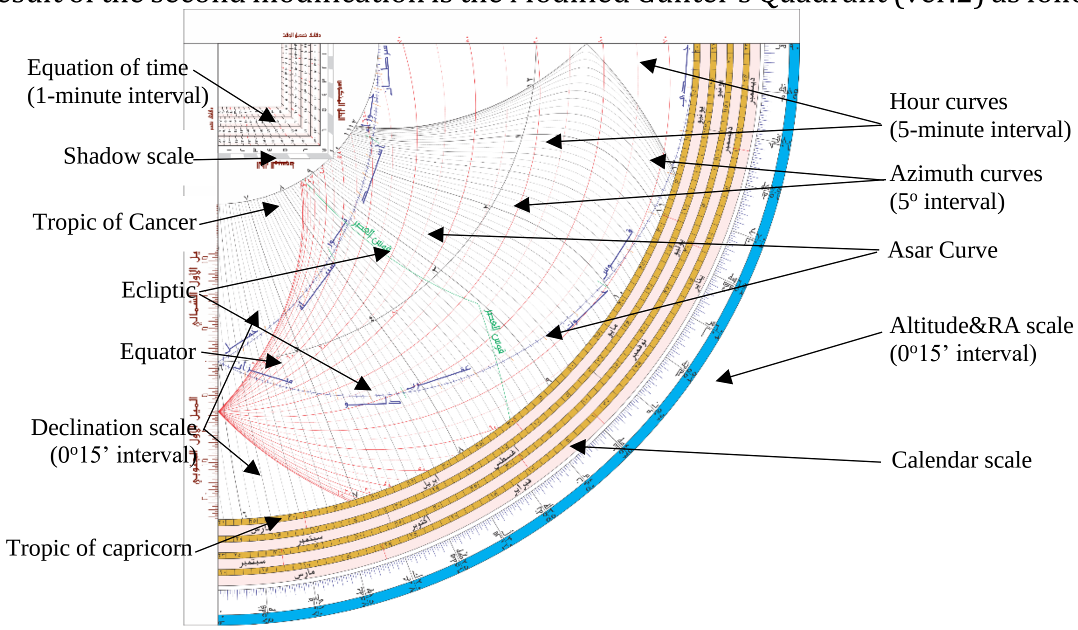

Figure 8. The Modified Gunter's Quadrant (ver.2)

The following is a comparison of the minimum scale for each of Gunter's Quadrant components between old Gunter's Quadrant, the Modified Gunter's Quadrant (ver.1), and the Modified Gunter's Quadrant (ver.2):

Table 4. The comparison of the minimum scale for each of Gunter's Quadrant components between old Gunter's Quadrant, the Modified Gunter's Quadrant (ver.1), and the Modified Gunter's Quadrant (ver.2)

No	Gunter's Quadrant Components	Minimum Scale used		
		Old Gunter's Quadrant	The Modified Gunter's Quadrant (ver.1)	The Modified Gunter's Quadrant (ver.2)
1	Quadrant arc (altitude and RA)	0^o 30'	0^o 15'	0^o 15'
2	Calendar Scale	5-8 days	1 day	1 day
3	Sun's declination	1^o	0^o 15'	0^o 15'
4	Equation of time	-	0^h 1^m	0^h 1^m
5	Sun's Longitude	5^o	1^o	1^o
6	Hour curves	0:30	0:15	0:05
7	Azimuth curves	10^o	10^o	5^o
8	Shadow scale	12arts	12 arts	12 arts

Description of Using Modified Gunter's Quadrant (Ver.2) in Prayer Times Calculation

1. To find the equation of time value

   Put the *Khait* (thread) on the desired date. On Modified Gunter's Quadrant (ver.2) there are 4 layers of the calendar scale. Look at the layer to what date and month were used. The layer of the calendar scale will determine at which layer the equation of time data is taken. If the chosen date and month are in the first layer, then the equation of time data is also taken from the first layer. If the date and month layers are in the second layer, then the equation of time data is also taken from the second layer, and so on.

2. To find the sun's declination

   On the Modified Gunter's Quadrant (ver.2), there are two ecliptic curves separated by the arc of the celestial equator. The upper ecliptic curve is used for the date and month in the first and second layers. While the lower ecliptic curve is used for the date and month which are in the third and fourth layers. The steps to find the sun's declination is as follows:

   a. Make sure the *Khait* (thread) position is still on the date used in the previous step to find the equation of time. Slide the *Muri* (bead) up to the ecliptic curve (the upper or lower ecliptic arc that is used depends on the layer of date and month used as mentioned above).
   b. Move the thread up to Modified Gunter's Quadrant arc 0^o. Look at the position of the bead on the *Mail al-Awwal* scale (sun's declination). Then that's the value of the declination on the date and month that is used.
   c. If the bead is in *Mail al-Awwal al-Syimaly,* then the sun's declination is positive (northern declination). If the bead is in *Mail al-Awwal al-Januby*, then the sun's declination is negative (southern declination).

3. To calculate Zuhur prayer time

   Calculating Zuhur prayer time is to calculate the sun's culmination time in the regional time system plus 3 minutes as time correction. Zuhur prayer time is calculated manually by the following formula:

   WK = 12 – EoT + (BD – BT) / 15 ....(11)

   or

   WK = 12 – EoT + regional time correction...(11)

   and

$Zh = WK + 0^h\ 3^m$ ....(12)

Zh : Zuhur prayer time
WK : Sun's culmination time
EoT : Equation of Time (obtained from the previous step)
BD : longitude of time zone
BT : longitude of the location

4. To calculate Asar prayer time
   a. Make sure the *Khait* (thread) position is still on the date used in the previous step to find the equation of time. Slide the *Muri* (bead) up to the ecliptic curve (the upper or lower ecliptic arc that is used depends on the layer of date and month used as mentioned above).
   b. Slide the thread until the bead's position is right on the green Asar curve.
   c. Look at the thread position on the arc of Modified Gunter's Quadrant (ver.2). The value shown by the thread is the altitude of the Sun at Asar.
   d. Look at the position of the bead on the row of hour curves. So that's the solar time for Asar prayer
   e. The Asar prayer time in the regional time system area can be calculated by adding up the solar time of the Asar prayer with the sun's culmination time.
5. To calculate Maghrib prayer time
   a. Place the *Khait* (thread) on the 0^o arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on the date used.
   b. Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 1^o arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's Maghrib prayer time
6. To calculate Isya prayer time
   a. Place the *Khait* (thread) on the 0^o arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on the date used.
   b. Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 17^o arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's Isya prayer time
7. To calculate Subuh prayer time
   a. Place the *Khait* (thread) on the 0^o arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on the date used.
   b. Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 19^o arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's Subuh prayer time

Accuracy of Modified Gunter's Quadrant (Ver.2) in Prayer Times Calculation

The Modified Gunter's Quadrant (ver.2) is a new model of Gunter's Quadrant that can be made for latitude near the equator and can be used in prayer times calculation with a better design than before (ver.1) and the accuracy of the hour curves has been improved. However, to be used in prayer times calculation, it is necessary to test the results of Modified Gunter's Quadrant (ver.2) in prayer time calculation to determine the feasibility and the accuracy of calculation results. At this stage, the accuracy test is carried out by comparing the results of the Sun's altitude and prayer times obtained from the Modified Gunter's Quadrant (ver.1) and the prayer times calculation using the Slamet Hambali's method in *Ilmu Falak 1* book and from the Modified Gunter's Quadrant (ver.2) and the prayer times calculation using the Slamet Hambali's Ephemeris method in *Ilmu Falak 1* book. The sun's ephemeris data used in this calculation is taken from Ephemeris Hisab Rukyat 2022 book and the calculation tool used is Microsoft Excel.

The coordinate of the location used in this test are as follows:

1. Latitude : 7° 25' S
2. Longitude : 109° 15' E
3. Elevation : 97 asl
4. Longitude of time zone : 105°
5. Regional time correction : $-0^h\ 17^m$
6. Dip : 0°1,76' x √tt: 0°18'17,43"

Using the location data above, the author tested the accuracy of prayer times calculation shown by Modified Gunter's Quadrant (ver.2) with calculations for February 27, April 17, May 5, and December 12, 2022. The selection of these months was to test the accuracy of the Modified Gunter's Quadrant (ver.2) calculation results when the sun is in the northern and southern hemispheres. The comparison results of prayer times calculation between Gunter's Quadrant and Ephemeris method with the modern calculator (MS. Excel) are as follows:

1. Prayer time calculation on February 27, 2022
   a. To find the equation of time on February 27

      Put the *Khait* (thread) on the February 27 date. It is on the fourth layer. Look at the equation of time scale on the fourth layer indicated by the *Khait* (thread). Then the equation of time on February 27 is -0^h13^m.

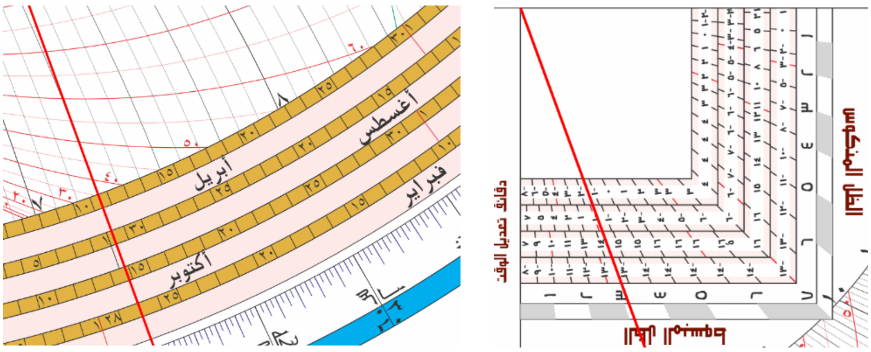

Figure 9. [Left] The *Khait* is Placed on The February 27 Date. [Right] The *Khait* on the Equation of Time Scale Shows the Equation of Time on 27 February: -0^h13^m

   b. To find Sun's declination on February 27

      Make sure the *Khait* (thread) position is still on February 27 in the previous step to find the equation of time. Slide the Muri (bead) up to the ecliptic curve. Move the thread up to Modified Gunter's Quadrant arc 0°. Look at the position of the bead on the *Mail al-*

Awwal scale (sun's declination). Then the value of the declination on February 27 is $8^o30'$ *Januby* or $-8^o30'$

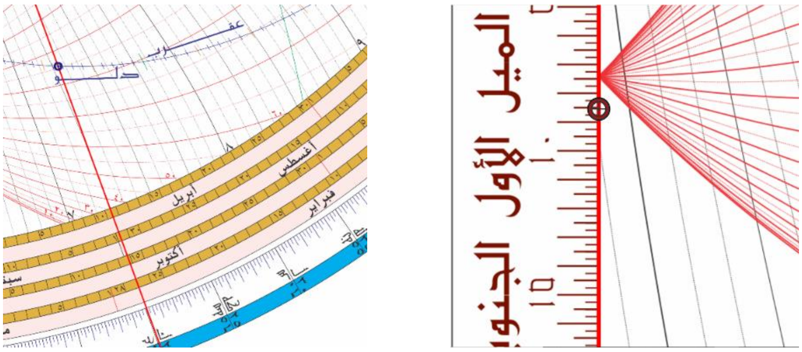

Figure 10. [Left] The *Khait* is Placed on the February 27 Date and The *Muri is* on The Curve of Ecliptic. [Right] The *Khait* is Placed on Modified Gunter's Quadrant Arc 0^o and the Bead on the *Mail Al-Awwal* Scale (Sun's Declination) Shows the Value of Sun's Declination: $8^o30'$ *Januby.*

c. To calculate Zuhur prayer time on February 27

Zuhur prayer time is calculated manually by the formula (11) for calculating the sun's culmination time and formula (12) for calculating zhuhur prayer time mentioned above:

$WK = 12 - -0^h13^m + -0^h17^m$
$= 11^h56^m$
$Zh = 11^h56^m + 0^h\ 3^m$
$= 11^h59^m$
= 11:59 WIB

d. To calculate Ashar prayer time on February 27

Make sure the *Khait* (thread) position is still on February 27 and the *Muri* (bead) is up to the ecliptic curve. Slide the thread until the bead's position is right on the green Asar curve. Look at the thread position on the arc of Modified Gunter's Quadrant (ver.2). The value shown by the thread is the altitude of the Sun at Asar, it is $44^o30'$. And the position of the bead on the row of hour curves is solar time for Asar prayer: 3^h4^m

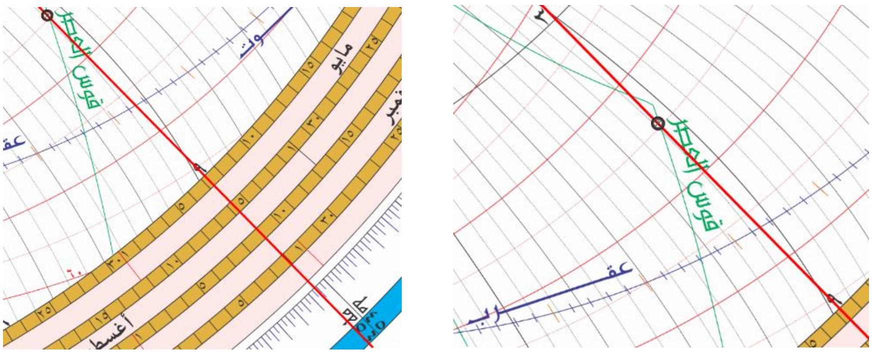

Figure 11. [Left] The *Khait* is Slided Until the *Muri* is Placed on the Curve of Asar. [Right] The Position of the Bead on the Row of Hour Curves is Solar Time for Asar Prayer: 3^h4^m

The Asar prayer time in the regional time system area can be calculated by adding up the sun's culmination time with the solar time of the Asar prayer:

Asar = WK + ST_{Asr} .... (13)

$= 11^h56^m + 3^h4^m$

$= 15^h00^m$

= 15:00 WIB

e. To calculate Maghrib prayer time on February 27

Place the *Khait* (thread) on the 0° arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on February 27. Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 1° arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's solar time for Maghrib prayer time: 6^h8^m

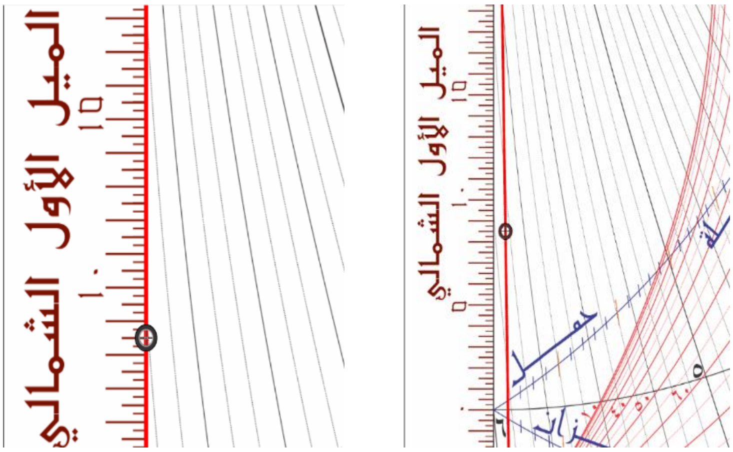

Figure 12. [Left] The *Muri* is Placed on the Reverse Declination Scale: 8°30' *Symaly*
[Right] The *Khait* is Placed on the Arc Of 1° and the Position of the Bead on the Row of Hour Curves is Solar Time for Maghrib Prayer: 6^h8^m

The Maghrib prayer time in the regional time system area can be calculated by adding up the sun's culmination time with the solar time of the Maghrib prayer time:

Maghrib = WK + ST_{Magh} .... (14)

$= 11^h56^m + 6^h8^m$

$= 18^h04^m$

= 18:04 WIB

f. To calculate Isya prayer time on February 27

Place the *Khait* (thread) on the 0° arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on the date used.

Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 18° arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's Isya prayer time: 7^h18^m.

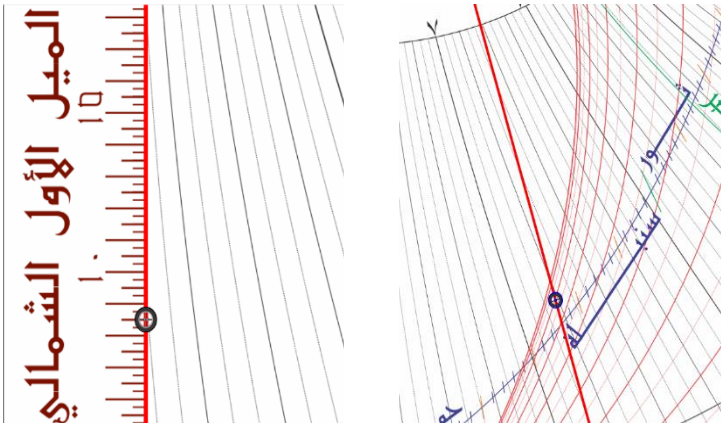

Figure 12. [Left] The *Muri* is Placed on the Reverse Declination Scale: 8°30' *Syimaly.* [Right] The *Khait* is Placed on the Arc of 18° and the Position of the Bead on the Row of Hour Curves is Solar Time for Isya Prayer: 7^h18^m

The Isya prayer time in the regional time system area can be calculated by adding up the sun's culmination time with the solar time of the Isya prayer time:

Isya $= WK + ST_{Isy}$ .... (15)

$= 11^h56^m + 7^h18^m$

$= 19^h14^m$

= 19:14 WIB

g. To calculate Subuh prayer time on February 27

Place the *Khait* (thread) on the 0° arc of Modified Gunter's Quadrant (ver.2) and make sure the position of the *Muri* (bead) is still at the value of the sun's declination on the date used.

Slide the bead until it is at the value of the sun's declination on the reverse scale. If previously the bead was on the *Mail al-Awwal al-Syimaly* scale, then slide it until it is at the same value on the *Mail al-Awwal al-Januby* scale. Likewise, if it's the other way around (from *Mail al-Awwal al-Januby* to *Mail al-Awwal al-Syimaly*). Then slide the thread until it is on the value of 19° arc of Modified Gunter's Quadrant (ver.2). Then look at the position of the bead on the row of hour curves. Then that's solar time for Subuh prayer time: 4^h33^m

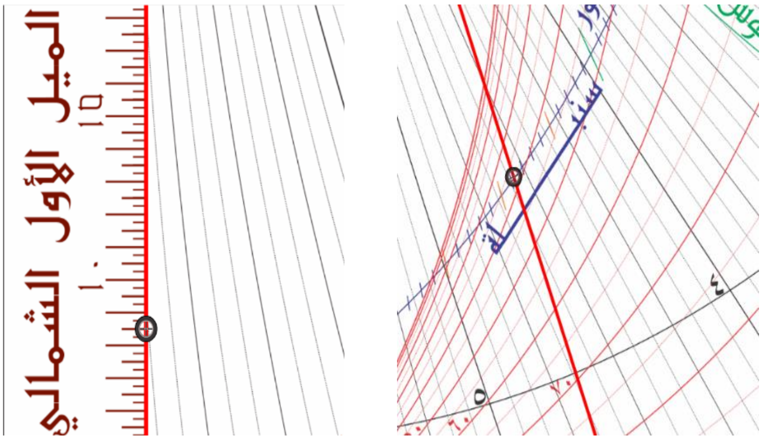

Figure 13. [Left] The *Muri* is Placed on the Reverse Declination Scale: 8°30' *Syimaly* [Right] The *Khait* is Placed on the Arc Of 20° and The Position of the Bead on the Row of Hour Curves is Solar Time for Subuh Prayer: 4^h33^m

The Subuh prayer time in the regional time system area can be calculated by the following formula:

Subuh = ST_{Sub} – EoT + regional time correction............ (16)
= 4^h33^m – -0h13 + -0^h17^m
= 4^h29^m
= 04:29 WIB

The following is a comparison table of the prayer time calculation results between Modified Gunter's Quadrant (ver.1), Modified Gunter's Quadrant (ver.2), and Ephemeris on February 27, 2022:

Table 5. Comparison of Prayer Times Calculation Results Between Modified Gunter's Quadrant (Ver.1), Modified Gunter's Quadrant (Ver.2), and Ephemeris Method on February 27, 2022

No	The Compared Data	Calculation Method			Difference between MGQ (ver.1) and Ephemeris	Difference between MGQ (ver.2) and Ephemeris
		Modified Gunter's Quadrant (ver.1)	Modified Gunter's Quadrant (ver.2)	Ephemeris		
1	Sun's declination	-8°30'	-8°30'	-8°21'23''	0°08'37''	0°08'37''
2	Equation of time	-0^h14^m	-0^h13^m	$-0^h12^m45^s$	$0^h01^m15^s$	$0^h00^m15^s$
3	Zuhur prayer time	11:57 WIB	11:59 WIB	11:58:45 WIB	00:01:45	00:00:15
4	Sun's altitude at Asar	44°30'	44°30'	44°32'2''	0°02'2''	0°02'2''
5	Asar prayer time	15:2:0 WIB	15:0:0 WIB	14:59:25 WIB	00:02:35	00:00:35
6	Sun's altitude at Maghrib	-1°	-1°	-1°7'20''	0°07'20''	0°07'20''
7	Maghrib prayer time	18:07:0 WIB	18:04:0 WIB	18:04:43 WIB	00:02:17	00:00:43
8	Sun's altitude at Isya	-18°	-18°	-18°7'20''	0°07'20''	0°07'20''
9	Isya prayer time	19:17:19	19:14:0 WIB	19:14:19 WIB	00:02:41	00:00:19
10	Sun's altitude at Subuh	-20°	-20°	-20°7'20''	0°07'20''	0°07'20''
11	Subuh prayer time	4:31:0	4:29:0 WIB	4:28:57 WIB	00:02:03	00:00:03

2. Prayer time calculation on April 17, 2022

The following is a comparison table of the prayer time calculation results between Modified Gunter's Quadrant (ver.1), Modified Gunter's Quadrant (ver.2), and Ephemeris on April 17, 2022:

Table 6. Comparison of Prayer Times Calculation Results Between Modified Gunter's Quadrant (Ver.1), Modified Gunter's Quadrant (Ver.2), and Ephemeris Method on April 17, 2022

No	The Compared Data	Calculation Method			Difference between MGQ (ver.1) and Ephemeris	Difference between MGQ (ver.2) and Ephemeris
		Modified Gunter's Quadrant (ver.1)	Modified Gunter's Quadrant (ver.2)	Ephemeris		
1	Sun's declination	10°30'	10°30'	10°27'57''	0°02'03''	0°02'03''
2	Equation of time	0^h1^m	0^h0^m	$0^h0^m22^s$	$0^h00^m38^s$	$0^h00^m22^s$
3	Zuhur prayer time	11:44:0 WIB	11:46:0 WIB	11:45:38 WIB	00:01:38	00:00:22
4	Sun's altitude at Asar	37°15'	37°0'	37°5'29''	0°09'29''	0°05'29''
5	Asar prayer time	15:05:0	15:03:0 WIB	15:2:43 WIB	00:02:17	00:00:17

6	Sun's altitude at Maghrib	-1°	-1°	-1°7'20''	0°07'20''	0°07'20''
7	Maghrib prayer time	17:45:0	17:41:0 WIB	17:41:44 WIB	00:03:16	00:00:44
8	Sun's altitude at Isya	-18°	-18°	-18°7'20''	0°07'20''	0°07'20''
9	Isya prayer time	18:53:0	18:51:0 WIB	18:51:15 WIB	00:01:45	00:00:15
10	Sun's altitude at Subuh	-19°30'	-19°30'	-19°37'17''	0°07'17''	0°07'17''
11	Subuh prayer time	4:28:0	4:26:0 WIB	4:25:52 WIB	00:02:08	00:00:08

3. Prayer time calculation on May 5, 2022

   The following is a comparison table of the prayer time calculation results between Modified Gunter's Quadrant (ver.1), Modified Gunter's Quadrant (ver.2), and Ephemeris on May 5, 2022:

Table 7. Comparison of Prayer Times Calculation Results Between Modified Gunter's Quadrant (Ver.1), Modified Gunter's Quadrant (Ver.2), and Ephemeris Method on May 5, 2022

No	The Compared Data	Calculation Method			Difference between MGQ (ver.1) and Ephemeris	Difference between MGQ (ver.2) and Ephemeris
		Modified Gunter's Quadrant (ver.1)	Modified Gunter's Quadrant (ver.2)	Ephemeris		
1	Sun's declination	16°14'	16°15'	16°14'48''	0°00'34''	0°00'12"
2	Equation of time	0^h3^m	0^h3^m	$0^h3^m16^s$	$0^h00^m16^s$	$0^h00^m16^s$
3	Zuhur prayer time	11:43:0 WIB	11:43:0 WIB	11:42:44 WIB	00:00:16	00:00:16
4	Sun's altitude at Asar	34°50'	34°45'	34°48'41''	0°02'19''	0°02'19''
5	Asar prayer time	15:04:00	15:02:0 WIB	15:01:17 WIB	00:02:43	00:00:43
6	Sun's altitude at Maghrib	-1°	-1°	-1°7'20''	0°07'20''	0°07'20''
7	Maghrib prayer time	17:38:0	17:36:0 WIB	17:35:45 WIB	00:03:15	00:00:15
8	Sun's altitude at Isya	-18°	-18°	-18°7'20''	0°07'17''	0°07'17''
9	Isya prayer time	18:47:0	18:47:0 WIB	18:46:52 WIB	00:01:08	00:00:08
10	Sun's altitude at Subuh	-20°	-20°	-20°7'20''	0°07'20''	0°07'20''
11	Subuh prayer time	4:27:0	4:25:0 WIB	4:24:15 WIB	00:01:45	00:00:45

4. Prayer time calculation on December 12, 2022

   The following is a comparison table of the prayer time calculation results between Modified Gunter's Quadrant (ver.1), Modified Gunter's Quadrant (ver.2), and Ephemeris on December 12, 2022:

Table 8. Comparison of Prayer Times Calculation Results Between Modified Gunter's Quadrant (Ver.1), Modified Gunter's Quadrant (Ver.2), and Ephemeris Method on December 12, 2022

No	The Compared Data	Calculation Method			Difference between MGQ (ver.1) and Ephemeris	Difference between MGQ (ver.2) and Ephemeris
		Modified Gunter's Quadrant (ver.1)	Modified Gunter's Quadrant (ver.2)	Ephemeris		
1	Sun's declination	-23°10'	-23°	-23°4'15''	0°05'45''	0°03'45''
2	Equation of time	0^h6^m	0^h6^m	$0^h6^m26^s$	$0^h00^m26^s$	$0^h00^m26^s$
3	Zuhur prayer time	11:40:0 WIB	11:40:0 WIB	11:39:34 WIB	00:00:26	00:00:26

4	Sun's altitude at Asar	38°10'	38°0'	37°59'38''	0°10'22''	0°00'22''
5	Asar prayer time	15:7:0	15:4:0 WIB	15:3:31 WIB	00:03:29	00:00:29
6	Sun's altitude at Maghrib	-1°	-1°	-1°7'20''	0°07'20''	0°07'20''
7	Maghrib prayer time	17:57:0	17:54:0 WIB	17:54:13 WIB	00:02:13	00:00:13
8	Sun's altitude at Isya	-18°	-18°	-18°7'20''	0°07'20''	0°07'20''
9	Isya prayer time	19:12:0	19:10:0 WIB	19:09:59 WIB	00:02:01	00:00:01
10	Sun's altitude at Subuh	-20°	-20°	-20°7'20''	0°07'20''	0°07'20''
11	Subuh prayer time	3:57:0	3:54:0 WIB	3:54:3 WIB	00:02:57	00:00:03

Based on these four tests above, it can be said that the results of prayer time calculation obtained from Gunter's Quadrant have various differences from the calculation results. The following is a recapitulation of the maximum and minimum differences from the above tests:

Table 9. Recapitulation of the Difference Results in Prayer Times Calculation Between Modified Gunter's Quadrant (Ver.1), Modified Gunter's Quadrant (Ver.2), and Ephemeris Method

No	The Compared Data	Difference between MGQ (ver.1) and Ephemeris		Difference between MGQ (ver.2) and Ephemeris	
		Maximum	Minimum	Maximum	Minimum
1	Sun's declination	0°08'37''	0°00'34''	0°08'37''	0°00'12''
2	Equation of time	$0^h01^m15^s$	$0^h00^m15^s$	$0^h00^m26^s$	$0^h00^m15^s$
3	Zuhur prayer time	00:01:38	00:00:16	00:00:26	00:00:15
4	Sun's altitude at Asar	0°10'22''	0°02'02''	0°5'29''	0°00'22''
5	Asar prayer time	00:03:29	00:02:17	00:00:43	00:00:17
6	Sun's altitude at Maghrib	0°07'20''	0°07'20''	0°07'20''	0°07'20''
7	Maghrib prayer time	00:03:16	00:02:13	00:00:44	00:00:13
8	Sun's altitude at Isya	0°07'20''	0°07'20''	0°07'20''	0°07'20''
9	Isya prayer time	00:02:01	00:01:08	00:00:19	00:00:01
10	Sun's altitude at Subuh	0°07'20''	0°07'20''	0°07'20''	0°07'20''
11	Subuh prayer time	00:02:57	00:01:45	00:00:45	00:00:03

Based on the recapitulation table of the different results in the prayer times calculation obtained from the Modified Gunter's Quadrant (ver.1), the Modified Gunter's Quadrant (ver.2), and the Ephemeris calculation method, it can be concluded that the level of accuracy of the Modified Gunter's Quadrant (ver.2) in prayer times calculation is better than the previous version of Modified Gunter's Quadrant (ver.1). The maximum difference between the results of prayer times calculation using the Modified Gunter's Quadrant (ver.1) with the ephemeris method reaches 3 minutes 29 seconds. While The maximum difference between the results of prayer times calculation using the Modified Gunter's Quadrant (ver.2) with the ephemeris method reaches only 0 minutes 45 seconds.

The Modified Gunter's Quadrant (ver.2) gets better prayer times calculation results than the previous version because it uses the latest sun's Ephemeris data and has used the hour curve projection method that is better than before with a 5-minute scale accuracy. So it can be said that the Modified Gunter's Quadrant (ver.2) is fairly good for an instrument that is easy to use in prayer times calculation. This can be seen from the minimum difference in the calculation results of prayer time using the Modified Gunter's Quadrant (ver.2) which can reach less than 1 minute compared to the calculation results using the sun's ephemeris data and modern calculators. From the 20 comparisons of prayer times, only 5 prayer times have a difference of more than 30 seconds with a maximum difference of 0 minutes 45 seconds.

The results of the Modified Gunter's Quadrant (ver.2) accuracy test in the prayer times calculation that has been done, can only provide an overview of the instrument's accuracy in the prayer times calculation. The results of this accuracy test indicate that the Modified Gunter's Quadrant (ver.2) is good enough to be used as a guide tool for determining the beginning of prayer times. This is because the Sun's data in Gunter's Quadrant is fixed and without correction for years later. So that its use for years to come has the potential to cause larger errors. However, the results of the accuracy test show that the maximum error of the calculation results is not more than 1 minute. So it can be concluded that the Modified Gunter's Quadrant (ver.2) can be used as a tool that can be used for calculating prayer times with fairly good accuracy.

CONCLUSION

Modification of Gunter's Quadrant as an instrument for calculating the beginning of prayer times is an attempt to eliminate the drawbacks of Gunter's Quadrant by adding curves and other parts needed in calculating the beginning of prayer times. Modification of Gunter's Quadrant is also not limited to adding a prayer time calculation function because the instrument made by Edmund Gunter also has flaws in its basic design that cannot be applied to small latitudes or locations that are close to the equator. On the Modified Gunter's Quadrant (ver.1), the author has changed the projection of the ecliptic arc from 90^{o} to 180^{o}, added the projection of the tropic circle from one to two, divided the sun's hour and azimuth curves based on the northern and southern declinations, changed the sun's ephemeris database, changed the system calendar scaling. The modification of Gunter's Quadrant for the reckoning function of prayer time is the addition of the Asar prayer time curve based on the Sun's altitude and the equation of time scale. The second modification of Gunter's Quadrant that author has done results in a Modified Gunter's Quadrant (ver.2), the type that can eliminate aesthetic deficiencies in the previous model design (ver.1) and improve the accuracy of the resulting time because it contains more hour curves that have a smaller time interval of 5-minute.

The results of the accuracy test using the modified Gunter's Quadrant in the initial reckoning of prayer times indicate that the prayer times obtained from the modified Gunter's Quadrant are different when compared to modern calculations. Of the 20 comparisons of prayer times, there are only 4 prayer times that have a difference of more than 30 seconds with a maximum difference of 45 seconds. Based on the accuracy test, it was concluded that the results of prayer time calculation obtained from Modified Gunter's Quadrant (ver.2) are quite good to be used as an instrument for calculating the beginning of prayer times. The accuracy level of the Modified Gunter's Quadrant (ver.2) has increased and it is much better than the previous version (ver.1).

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