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Ionospheric Research

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Scientific Report

on

"The Measurement of Phase and Amplitude Radio Wave Interaction at University Park, Pennsylvania October - November 1965"

by

A. J. Ferraro and H. S. Lee

March 15, 1966

Scientific Report No. 266

(Project 8605, Task 860502)

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Ionosphere Research Laboratory

Approved for Distribution

A. H. Waynick, Director, I.R.L.

The Pennsylvania State University

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Abstract

This report presents the data obtained from the measurement of phase and amplitude radio wave interaction during the period of October 1, 1965 through November 30, 1965. The work was carried out at the Ionosphere Research Laboratory, The Pennsylvania State University, (N. Lat. 40°-47', W. Long. 77° - 57'), University Park, Pennsylvania, U.S.A. The present work is categorized as "Miscellaneous Measurements" in the discipline of "Ionosphere" in the IQSY program.

Introduction

This report describes the results of the measurement of phase and amplitude radio wave interaction made during the period of October 1, 1965 through November 30, 1965. The work was carried out at the Ionosphere Research Laboratory, The Pennsylvania State University (N. Lat. 40° -47', W. Long. 77° -57'), University Park, Pennsylvania, U.S.A. The present work is categorized as "Miscellaneous Measurements" in the discipline of "Ionosphere" in the IQSY program.

The objective of the present work is to study the properties of ionospheric D-region using radio wave interaction effect which is also commonly known as Luxembourg effect. The present technique closely follows that developed by Fejer (1955) for radio wave amplitude interaction experiment. However, the technique of measurement as well as the theory of radio wave interaction have been extended and generalized at the Ionosphere Research Laboratory by the introduction of complex coefficient of interaction T, to embody the effect of interaction on both the amplitude and the phase of radio waves.

Radio wave interaction, or the Luxembourg effect, depends upon the fact that a so-called "disturbing" transmitter can impart energy to the electrons of the ionosphere in the height range of interest and hence increase their thermal energy and, consequently, the collision frequency. Another radio signal from a "wanted" transmitter, in passing through this region, will suffer a slightly greater attenuation than it would if the disturbing transmitter were non-operative. Fejer employed pulse transmissions for both the disturbing and wanted signals with the former having a pulse repetition rate of one-half the latter. In this manner,

every other "wanted" pulse would be affected by the increased absorption introduced by the disturbing transmitter. Furthermore, by changing the time-delay between the keying of the two transmitters, the highest height level at which interaction can occur is controlled. With this scheme, Fejer was able to deduce preliminary height profiles of electron density and collision frequency.

It is quite obvious that if the ionospheric medium is disturbed by a high power transmitter there will be an increase in the electron temperature which manifests itself as a change in collision frequency which, in turn, produces a small perturbation in the imaginary and real parts of the local complex refractive index. This change in the imaginary part of the index is responsible for the amplitude interaction effect which Fejer and other workers have studied in the past with a great deal of success. Corresponding to the perturbation in the real part of the index, there should be a small change in the phase of the wanted radio frequency carrier; this will be termed phase interaction. This effect had never been observed before or considered as a possible technique for the study of the lower ionosphere.

Basis of Measurements

The new technique for the measurement of phase interaction and the derivation of generalized complex coefficient of interaction T in the theory of radio wave interaction are described in detail by Weisbrod (1964) and Weisbrod, et al. (1964). The expression of the complex coefficient necessary for the interpretation of the data tabulated in this report is given below.

$$T = T_A + jT_\varphi = \int_o^{h'_i} \frac{T_h(1 - e^{-G\nu\tau})}{G\nu\tau} \exp\left[\frac{-2G\nu(h'_i - h)}{c}\right] \left(\frac{-\partial F}{\partial h}\right) dh$$

$$+ \int_{h'_i}^{h_i} \frac{T_h}{G\nu\tau} \left\{1 - \exp\left[\frac{-2G\nu(h_i - h)}{c}\right]\right\} \left(\frac{-\partial F}{\partial h}\right) dh$$

where

$T_A = \frac{\Delta A}{A}$ = Fractional change in the amplitude of wanted signal due to radio wave interaction.

$T_\varphi = \Delta\varphi$ = Differential change in the phase of wanted signal due to radio wave interaction.

$$T_h = T_{hA} + jT_{h\varphi} = \frac{\alpha}{h^2} \frac{Z}{[(1 \pm Y_L) - jZ]^2}$$

$$\alpha = \frac{e^2 P_D G_D \tau \beta}{12\pi k \Theta m \varepsilon_o \omega^2}$$

P_D = Disturbing transmitter power

G_D = Disturbing antenna gain

h = Height variable

τ = Duration of disturbing pulse

k = Boltzmann constant

e = Electron charge

m = Electron mass

ε_o = Permittivity of free space

Θ = Electron temperature

ω = Angular frequency of wanted radio wave

β = Free space propagation constant ω/c

c = Velocity of light

G = Energy loss coefficient

ν = Electron collision frequency

h_i = The height at which the down-coming wanted signal meets the upgoing disturbing signal

$h_i' = h_i - \frac{c\tau}{2}$

$Z = \nu/\omega$

Y_L = Longitudinal component of Y

$Y = \omega_H/\omega$

ω_H = Angular gyro frequency

$$F = \exp \int_o^h [- 2 \beta_D \chi_D(h')] \, dh'$$

$\beta_D = \omega_D/c$

ω_D = Angular frequency of disturbing radio wave

h' = Dummy height variable

χ_D = Absorption index of disturbing radio wave

The quantities measured in the present experiment are the real and imaginary components of the complex coefficient of interaction T_A and T_φ, respectively. Various methods of obtaining electron density and collision frequency height profiles have been evaluated. These techniques appear in the Ionosphere Research Scientific Reports No. 220, 238, and 248.

Specifications of Experimental Facilities

	Wanted radio signal	Disturbing radio signal
Frequency	2.2 Mc/s	300 Kc/s
Pulse repetition rate	75 per sec.	37.5 per sec.
Pulse duration	50 μ sec.	150 μ sec.
Peak power	10 kw	100 kw
Polarization	circular polarization (ordinary)	linear polarization

With the above-given specifications, the order of magnitude of T_A and T_φ to be measured are 0.01% and 10^{-4} radians, respectively.

Presentation of Data

The data, T_A and T_φ, tabulated in this report were measured during daylight hours (approximately 0900 hours to 1600 hours EST) with the values of h_i varied from approximately 55 km to 95 km at 5 km steps. In view of the fact that the quantities to be measured were extremely small, it was necessary to integrate the effect over a period of 2.5 minutes and in some cases 5 minutes for each height of h_i. Due to strong interferences, it was impractical to make the measurements during the nighttime.

The data obtained during the months of October and November 1965 are tabulated on a daily basis with corresponding values of h_i indicated and with the time of beginning of each measurement interval given in Universal Time. The multiplication factor for both T_A and T_φ given in the table is 10^{-4} .

A distinction is made between a blank and a zero in the tabulation of data. The former indicates that the reliable data are not available

while the latter indicates that the interaction effect is nil within the resolution of the measurement. The interaction data, are qualified with a symbol to indicate the conditions under which the measurement was made. These symbols are essentially those standard symbols used in reporting ionospheric wind measurements except that the meaning associated with "N" has been modified slightly to fit the needs of the interaction program. These symbols are as defined below:

B - Measurement influenced by, or impossible because of, high non-deviative absorption.

N - Conditions are such that measurement cannot be readily interpreted because the echo pattern is changing too rapidly with time to permit reliable interaction measurements.

S - Measurement influenced by, or impossible because of, interference or atmospherics.

U - Uncertain or doubtful numerical value.

Table of T_A and T_φ

October 1965

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
1	1437.0	52	0.59		N
	1442.0	57	0.82		
	1447.0	62	0.35		N
	1452.0	67	0.82		
	1457.0	72	0.94		
	1502.0	77	0.47		
	1507.0	82	0.24		N
	1657.0	62	0.90		
	1702.0	67	1.70		
	1707.0	72	1.80		
	1712.0	77	1.40		
	1717.0	82	1.30		
	1757.0	52	-0.70		
	1802.0	57	1.0		
	1807.0	62	1.60		
	1812.0	67	1.20		
	1817.0	72	0.80		
	1822.0	77	1.10		
	1827.0	82	1.20		
	1857.0	52	0.70	0.89	
	1902.0	57	1.0	0.55	
	1907.0	62	0.90	1.11	
	1912.0	67	1.30	0.78	
	1917.0	72	1.20	0.22	
	1922.0	77	1.10	1.44	
	1927.0	82	1.10		N
	1932.0	87	1.40		U
3	1652.0	52	0.70	0.70	
	1657.0	57	0.60	0.80	
	1702.0	62	1.30	0.40	
	1707.0	67	1.90	0.60	
	1712.0	72	1.0	1.12	
	1717.0	77	0.82	0.37	
	1722.0	82		1.12	
	1747.0	52	0.27		N
	1752.0	57	1.18		
	1757.0	62	1.64		
	1802.0	67	1.73		
	1807.0	72	2.11		
	1812.0	77	1.11		
	1817.0	82	1.56		N, U

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
3	1927.0	62		0.67	
	1932.0	67		0.33	
	1937.0	72		0.78	
	1942.0	77		0.89	
	1947.0	82		1.0	
	1952.0	87		1.11	
4	1747.0	57	0.90		N
	1752.0	62	0.70		N
	1757.0	67	1.50		
	1802.0	72	1.20		
	1807.0	77	1.89		
	1812.0	82	0.63		
	1817.0	87	0.84		N, U
	1904.5	47	- 0.42		N
	1909.5	52	0.84		N
	1914.5	57	0.63		
	1919.5	62	0.95		
	1924.5	67	1.26		
	1929.5	72	1.10		
	1934.5	77	0.50		
	2017.0	57	0.80		
	2022.0	62	1.30		
	2027.0	67	1.30		N
	2032.0	72			
	2037.0	77	1.40		
5	1507.0	62	0.86		
	1512.0	67	1.43		
	1517.0	72	1.17		
	1522.0	77	0.83		
	1617.0	67	1.33		
	1622.0	72	1.44		
	1627.0	77	1.33		
	1632.0	82	1.0		
	1707.0	57	0.57		
	1712.0	62	0.71		
	1717.0	67	1.14		
	1722.0	72	1.17		
	1727.0	77	1.50		
	1807.0	57	1.26	1.05	
	1812.0	62	1.37	0.74	
	1817.0	67	2.0	0.74	
	1822.0	72	1.89	0.94	
	1827.0	77	0.84	0.47	
	1832.0	82	1.58	0.35	

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
5	1857.0	52		0.33	
	1902.0	57		0.55	
	1907.0	62		0.55	
	1912.0	67		0.22	
	1917.0	72		0.89	
	1922.0	77		0.44	
	1927.0	82		0.78	
6	1407.0	57	0.54		
	1412.0	62	0.82		
	1417.0	67	0.90		
	1422.0	72	1.91		
	1427.0	77	0.84		N
	1542.0	57	0.84		N
	1547.0	62	0.53		N
	1552.0	67	2.10		N
	1557.0	72	1.79		
	1602.0	77	1.22		
	1607.0	82	0.78		N
	1612.0	87	1.56		N, U
	1802.0	52	0.62	0.37	
	1807.0	57	0.77	0.50	
	1812.0	62	1.23	0.50	
	1817.0	67	0.62		
	1822.0	72	0.67	1.0	
	1827.0	77	0.67	1.0	
	1832.0	82		2.0	
	1837.0	87	0.53		
	1802.0	57	1.20	1.25	
	1807.0	62	1.07	1.0	
	1912.0	67	1.47	1.50	
	1917.0	72	1.33	1.75	
7	1607.0	62		0.67	
	1612.0	67		1.0	
	1617.0	72		1.07	
	1707.0	52	0.92		
	1712.0	57	1.0	1.07	
	1717.0	62	1.16	1.33	
	1722.0	67	1.16		
	1727.0	72	1.0	1.33	
	1732.0	77	1.80	2.44	

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
8	1527.0	52	0.27		
	1532.0	57			
	1537.0	62	0.73		
	1542.0	67	0.64		
	1547.0	72	1.27		
	1552.0	77	1.78		
	1557.0	82	1.11		N
	1632.0	52	0.33		N
	1637.0	57	0.44		N
	1642.0	62	0.89		
	1647.0	67	1.22		
	1652.0	72	1.33		
	1657.0	77	2.0		
	1702.0	82	1.40		N
9	1412.0	57	0.53		N
	1417.0	62	1.20		
	1422.0	67	1.07		N
	1427.0	72	1.47		
	1432.0	77	0.90		
	1437.0	82	1.09		
	1442.0	87	0.45		N
	1537.0	57	0.36		N
	1542.0	62	0.82		
	1547.0	67	0.90		
	1552.0	72	1.45		
	1557.0	77	1.36		
	1602.0	82	0.45		N
	1642.0	52	0.27		N
	1647.0	57	0.73		
	1652.0	62	0.90		
	1657.0	67	1.45		
	1702.0	72	0.64		
	1707.0	77	0.76		
	1712.0	82	1.24		N
	1747.0	52	0.57		N
	1752.0	57	0.38	0.32	N
	1757.0	62	1.05	0.42	
	1802.0	67	1.33	0.32	
	1807.0	72	1.52	0.53	
	1812.0	77	1.16		
	1817.0	82	0.50		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
9	1957.0	52	-0.27		N
	2002.0	57	0.36		N
	2007.0	62	0.64		
	2012.0	67	1.09		
	2017.0	72	1.18		
	2022.0	77	1.54		
	2027.0	82	1.18		
	2032.0	87	1.45		N, U
	2037.0	92	0.36		N, U
10	1622.0	57		1.50	
	1627.0	62	0.44		
	1632.0	67	1.56	1.25	
	1637.0	72	1.78	1.28	
	1642.0	77	1.78	1.14	
	1647.0	82	1.11		
	1707.0	52		0.57	
	1712.0	57	0.62	1.0	
	1717.0	62	1.12	1.43	
	1722.0	67	1.37	1.14	
	1727.0	72	1.62	1.20	
	1732.0	77	0.87	0.67	
	1737.0	82	0.75	0.40	
	1757.0	52	0.37		
	1802.0	57	0.75	0.40	
	1807.0	62	1.50	0.80	
	1812.0	67	1.87	0.93	
	1817.0	72	1.71	1.09	
	1822.0	77	1.86		
	1827.0	82	1.0		
	1849.5	57	0.86		
	1854.5	62	1.0		
	1859.5	67	0.86		N
	1904.5	72	1.50		
	1909.5	77	1.25		
	1914.5	82	0.62		N, U
11	1452.0	52	-0.50		
	1457.0	57	0.60		
	1502.0	62	1.10		
	1507.0	67	1.70		
	1512.0	72	1.80		
	1517.0	77	2.0		
	1522.0	82	0.80		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
11	1857.0	52	-0.62		N
	1902.0	57	1.0		
	1907.0	62	0.87		
	1912.0	67	1.75		
	1917.0	72	1.22		
	1922.0	77	1.33		
	1927.0	82	1.11		
	1954.5	57	0.40		
	1959.5	62	0.60		
	2004.5	67	0.80		
	2009.5	72			
	2014.5	77	0.80		
	2019.5	82	0.60		
12	1437.0	52	0.87		S
	1442.0	57	1.75		
	1447.0	62	1.87		
	1452.0	67	2.0		
	1457.0	72	2.37		
	1502.0	77	1.87		
	1507.0	82	0.53		S
	1557.0	52	0.93		
	1602.0	57	1.47		
	1607.0	62	0.80		N
	1612.0	67	1.87		
	1617.0	72	2.0		
	1622.0	77	1.76		
	1627.0	82	1.41		N, U
	1657.0	52	-0.59	0.71	N
	1702.0	57	1.18	1.43	
	1707.0	62	1.65	1.86	
	1712.0	67	1.53		N
	1717.0	72	1.50		N
	1722.0	77	1.87	1.25	N
	1837.0	62	1.40		
	1842.0	67	1.60		
	1847.0	72			
	1852.0	77	1.20		
13	1527.0	57	-0.30	1.05	N
	1532.0	62	1.0	1.26	
	1537.0	67	0.50	1.05	N
	1542.0	72	0.60	0.63	N
	1547.0	77	0.50	0.62	N
	1552.0	82	0.37		N

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
13	1642.0	57	0.62	0.75	N
	1647.0	62	1.0	1.0	N
	1652.0	67	1.50	1.50	N
	1657.0	67	0.75	1.50	
	1702.0	72	1.50	1.17	
	1707.0	77	0.50	1.33	N
	1837.0	52	1.0	0.62	N
	1842.0	57	1.12	1.12	N, U
	1847.0	62	1.0	1.0	N
	1852.0	67	0.87	1.12	N
	1857.0	72	1.33	0.42	N
	1902.0	77	0.93	0.84	N
	1937.0	57	1.16		
	1942.0	62			
	1947.0	67	0.63		
	1952.0	72	0.95		
	1957.0	77	0.42		
	2002.0	82	0.74		
	2007.0	87	0.53		
14	1712.0	52	-0.54		N
	1717.0	57	-0.27		N
	1722.0	62	0.27		N
	1727.0	67	0.73		N
	1732.0	72	1.0		N
	1737.0	77	0.54		N
	1742.0	82	0.54		N
	1837.0	67	0.80		
	1842.0	72	1.20		
	1847.0	77	1.20		
	1852.0	82	1.0		
15	1432.0	52	0.45		
	1437.0	57	0.54		
	1442.0	62	1.64		
	1447.0	67	1.54		
	1452.0	72	1.91		
	1457.0	77	2.0		
	1502.0	82	0.74		
	1507.0	87	1.16		N, U
	1607.0	52	1.16		N
	1612.0	57	0.84		
	1617.0	62	1.16		
	1622.0	67	2.0		
	1627.0	72	2.10		
	1632.0	77	1.62		
	1637.0	82	1.71		
	1642.0	87	1.05		N

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
15	1907.0	57		0.27	
	1912.0	62		1.07	
	1917.0	67		0.53	
	1922.0	72		0.93	
	1927.0	77		1.07	
	1932.0	82		0.80	
18	1542.0	57	-0.50		N
	1547.0	62	1.10		
	1552.0	67	1.50		
	1557.0	72	1.62		
	1602.0	77	0.67		
	1742.0	52	0.48		
	1747.0	57	0.95		
	1752.0	62	1.14		
	1757.0	67	1.60		
	1802.0	72	1.50		
	1807.0	77	0.50		
	1837.0	52	0.40		N
	1842.0	57	0.70		
	1847.0	62	1.20		
	1852.0	67	1.10		
	1857.0	72	1.40		
	1902.0	77	1.0		
	1907.0	82	0.90		
19	1427.0	52	0.36		N
	1437.0	57	0.36		N
	1442.0	62	0.28		N, U
	1447.0	67	0.57		
	1452.0	72	1.28		N
	1457.0	77	1.36		N
	1502.0	82	0.64		N
	1527.0	52	0.32		N
	1532.0	57	0.64		
	1537.0	62	1.28		
	1542.0	67	1.44		
	1547.0	72	0.64		
	1552.0	77	0.78		
	1557.0	82	0.86		N
	1642.0	52	-0.36		N
	1647.0	57	-0.21		N
	1652.0	62	1.07		
	1657.0	67	1.43		
	1702.0	72	1.57		
	1707.0	77	1.50		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
21	1432.0	52	0.30		N
	1437.0	57	0.90		N
	1442.0	62	0.70		
	1447.0	67	0.60		
	1452.0	72	1.14		
	1457.0	77	1.05		
	1502.0	82	0.95		
	1507.0	87	0.95		N
	1547.0	67	1.53		
	1552.0	72	2.12		
	1557.0	77	1.87		
	1602.0	82	1.12		
	1637.0	57	0.75		
	1642.0	62	1.37		
	1647.0	67	1.75		
	1652.0	72	1.37	0.67	
	1657.0	77	1.68	0.83	
	1702.0	82	0.74	1.0	
	1707.0	87		2.0	
	1932.0	52	0.62		S
	1937.0	57			
	1942.0	62	0.62		S
	1947.0	67	1.0		S
	1952.0	72	0.62		S
	1957.0	77	0.75		S
	2002.0	82	1.37		S
	2007.0	87	0.50		S
23	1437.0	52	0.25		
	1442.0	57	1.25		
	1447.0	62	1.25		
	1452.0	67	1.0		S
	1457.0	72	0.40		S
	1502.0	77	1.30		S
	1507.0	82	0.80		S
	1537.0	52	0.80		
	1542.0	57	1.0		
	1547.0	62	1.60		
	1552.0	67	1.80		
	1557.0	72	2.30		
	1602.0	77	1.80		
	1607.0	82	0.80		
	1632.0	52	-0.60		
	1637.0	57	1.10		
	1642.0	62	0.30		N
	1647.0	67	1.40		
	1652.0	72	1.70		
	1657.0	77	1.60		
	1702.0	82	1.0		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
23	1732.0	52	1.14		
	1737.0	57	1.57	1.33	
	1742.0	62	1.43	1.56	
	1747.0	67	1.71	0.89	
	1752.0	72	0.50		
	1757.0	77	1.10	1.78	
	1802.0	82	0.60	2.0	
	1832.0	52	0.28		S
	1837.0	57	0.57		S
	1842.0	62	1.05		
	1847.0	67	1.33		
	1852.0	72	1.14		S
	1857.0	77	0.57		
	1902.0	82	1.71		S, U
	1907.0	87	0.76		S, U
24	1637.0	52	0.57		N
	1642.0	57	0.86		
	1647.0	62	2.57		
	1652.0	67	2.0		
	1657.0	72	2.37		
	1702.0	77	1.62		
	1707.0	82	1.0		
	1732.0	52	1.12		
	1737.0	57	0.75		
	1742.0	62	1.25		
	1747.0	67	1.37		
	1752.0	72	1.80		
	1757.0	77	1.70		
	1802.0	82	1.30		
	1837.0	57	0.50		
	1842.0	62	0.90		
	1847.0	67	1.10		
	1852.0	72	1.20		
	1857.0	77			
	1902.0	82	1.30		
25	1432.0	52	-1.0		
	1437.0	57	0.75		
	1442.0	62	0.87		
	1447.0	67	1.0		
	1452.0	72	0.70		
	1457.0	77	1.30		
	1502.0	82	0.90		
	1507.0	87	0.60		
	1552.0	62	0.60		
	1557.0	67	1.10		
	1602.0	72	1.60		
	1607.0	77	1.30		

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
26	1432.0	52	0.20		N
	1437.0	57	0.40		N
	1442.0	62	0.30		N
	1447.0	67	0.60		
	1452.0	72	0.70		
	1457.0	77	1.70		
	1502.0	82	0.90		N
	1507.0	87	0.80		N
	1632.0	52	0.62		
	1637.0	57	0.37		
	1642.0	62	0.62		
	1647.0	67	0.75		
	1732.0	52	-0.16		N
	1737.0	57	-0.75		N, U
	1742.0	62	0.58		
	1747.0	67	0.84		
	1752.0	72	1.16		
	1757.0	77	1.08		N
27	1442.0	62	0.86		
	1447.0	67	1.28		
	1452.0	72	1,23		
	1457.0	77	0.46		
	1537.0	52	0.46		
	1542.0	57			
	1547.0	62	0.92		
	1552.0	67	0.85		
	1557.0	72	0.95		
	1602.0	77	0.76		
	1607.0	82	0.67		
	1632.0	52	-0.74		N
	1637.0	57	0.84		
	1642.0	62	1.58		
	1647.0	67	1.26		
	1652.0	72	1.28		
	1657.0	77	0.86		N
	1702.0	82	0.71		
	1737.0	52	-0.57		N
	1742.0	57	1.43		
	1747.0	62	1.86		
	1752.0	67	2.14		
	1757.0	72	1.64		
	1802.0	77	1.09		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
28	1632.0	52	-0.40		N
	1637.0	57	0.30		N
	1642.0	62	1.30		N
	1647.0	67	1.50		N
	1652.0	72	1.20		N
	1657.0	77	0.70		N
29	1637.0	57	0.17		
	1642.0	62	0.70		
	1647.0	67	0.70		
	1652.0	72	1.26		
	1657.0	77	1.37		
	1702.0	82	1.16		
	1832.0	52	-0.13		N
	1837.0	57	-0.52		N
	1842.0	62	0.39		
	1847.0	67	0.64		
	1852.0	72	0.84		
	1857.0	77	0.90		
30	1442.0	62	0.33		
	1447.0	67	0.78		
	1452.0	72	0.93		
	1457.0	77	0.86		
	1502.0	82	0.71		
	1532.0	52	-0.48		N
	1537.0	57	0.38		
	1542.0	62	0.67		
	1547.0	67	1.24		
	1552.0	72	1.44		
	1557.0	77	1.56		
	1632.0	52	-0.89		N
	1637.0	57	-0.78		N
	1642.0	62	0.22		N
	1647.0	67	1.44		
	1652.0	72	1.79		
	1657.0	77	1.37		
31	1632.0	52	-1.33		N
	1637.0	57	-0.67		N
	1642.0	62	0.78		
	1647.0	67	1.33		
	1652.0	72	1.33		
	1657.0	77	1.20		
	1702.0	82	1.07		
	1707.0	87	1.60		N

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
31	1747.0	67		1.56	
	1752.0	72		1.09	
	1757.0	77		1.27	
	1802.0	82		0.91	

Table of T_A and T_φ

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Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
1	1532.0	52	-0.42		
	1537.0	57	-0.16		
	1542.0	62	-0.75		
	1547.0	67	0.42		
	1552.0	72	1.25		
	1557.0	77	1.0		
	1602.0	82	0.87		
	1607.0	87	0.50		
2	1542.0	62	0.44		N
	1547.0	67	1.11		
	1552.0	72	0.85		
	1557.0	77	0.62		
	1832.0	52	-0.75		N
	1837.0	57	-0.92	0.75	N
	1842.0	62	0.33	1.75	
	1847.0	67	1.33	1.25	
	1852.0	72	0.92	1.50	
	1857.0	77	1.08	1.50	
	1902.0	82	0.50	1.0	
4	1447.0	52	-0.63		
	1452.0	57	-0.42		
	1457.0	62	0.32		
	1502.0	67	0.74		
	1507.0	72	1.18		
	1512.0	77	0.24		
	1557.0	52	-1.06		
	1602.0	57	-0.47		
	1607.0	62	-0.35		
	1612.0	67	0.94		
	1617.0	72	1.0		
	1622.0	77	0.86		
5	1637.0	52	-0.63		N
	1642.0	57	0.21		N
	1647.0	62	0.21		N
	1652.0	67	0.53		N
	1657.0	72	0.67		N
	1742.0	62		1.0	N
	1747.0	67		2.33	N
	1752.0	72		2.67	N
	1757.0	77		3.33	N

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
6	1537.0	52	-0.18	1.25	N
	1542.0	57	0.27	1.50	
	1547.0	62	0.82		
	1552.0	67	1.27	1.0	
	1557.0	72	1.40	0.75	
8	1457.0	52	-0.44		N
	1502.0	57	0.44		
	1507.0	62	0.55		
	1512.0	67	0.78		
	1517.0	72	1.89		
	1522.0	77	2.33		
	1527.0	82	1.89		
	1532.0	87	1.0		
	1732.0	52	0.35	0.89	
	1737.0	57	0.94	1.11	
	1742.0	62	1.76	1.33	
	1747.0	67	1.29	1.11	
	1752.0	72	1.41	2.22	
	1757.0	77	0.59	1.40	
	1802.0	82	1.53	0.60	N
	1837.0	52	0.47	1.40	
	1842.0	57	0.70	1.0	
	1847.0	62	0.35	0.60	
	1852.0	67	1.41	1.20	
	1857.0	72	1.53	2.20	
	1902.0	77	1.22	2.33	
	1907.0	82	1.0	2.33	
	1912.0	87	0.67		
9	1507.0	52	-0.54		N
	1512.0	57	0.90		
	1517.0	62	1.27		
	1522.0	67	1.56		
	1527.0	72	2.22		N
	1532.0	77	1.33		
	1632.0	52	0.33		
	1637.0	57	0.66		
	1642.0	62	0.84		
	1647.0	67	0.92		
	1652.0	72	0.67		
	1852.0	52	-0.34		
	1857.0	57	-0.21		
	1902.0	62	0.55		
	1907.0	67	0.90		
	1912.0	72	0.62		

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
10	1832.0	52	0.50		
	1837.0	57	0.67	0.44	
	1842.0	62	0.67	0.67	
	1847.0	67	1.33	0.67	
	1852.0	72	0.54		
	1857.0	77	0.45		
	1927.0	52	-0.54		
	1932.0	57	0.27		
	1937.0	62	0.73		
	1942.0	67	1.0		
	1947.0	72	0.36		
	1952.0	77	0.54		
12	1432.0	52	0.18		
	1437.0	57	0.54		
	1442.0	62	0.82		
	1447.0	67	0.73		
	1452.0	72	0.45		
	1457.0	77	1.16		
	1502.0	82	0.50		
	1702.0	52	-0.86		N
	1707.0	57	0.57		
	1712.0	62	0.28		
	1717.0	67	0.76		
	1722.0	72	1.43		
	1727.0	77	1.27		
	1732.0	82	0.90		
	1737.0	87	0.90		
	1842.0	52	-0.18		N
	1847.0	57	1.0		
	1852.0	62	0.73		
	1857.0	67	0.73		
	1902.0	72	1.36		
	1907.0	77	1.27		
	1912.0	82	0.54		
13	1647.0	52	0.36		
	1652.0	57	0.57		
	1657.0	62	0.57		
	1702.0	67	0.64		
	1707.0	72	0.71		
	1712.0	77	0.64		
	1717.0	82	0.21		

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
13	1812.0	52	-0.38		
	1822.0	57	0.31		
	1827.0	62			
	1832.0	67	1.0		
	1837.0	72	1.23		
	1842.0	77	1.31		
	1847.0	82	1.23		
	1852.0	87	0.62		
16	1842.0	52	0.50		
	1847.0	57	1.20		
	1852.0	62	1.40		
	1857.0	67	1.60		
	1902.0	72	2.20		
	1907.0	77	1.60		
	1912.0	82	1.30		
	1917.0	87	1.0		
	1922.0	92	0.60		
17	1452.0	52	-0.23		N
	1457.0	57	0.54		
	1502.0	62	0.69		
	1507.0	67	0.77		
	1512.0	72	0.46		
	1517.0	77	1.38		
	1522.0	82	0.85		
	1527.0	87	0.54		N
18	1802.0	52	0.25		
	1807.0	57	0.58		
	1812.0	62	0.42		
	1817.0	67	0.92		
	1822.0	72	0.66		
19	1602.0	52	0.14		
	1607.0	57	0.21		
	1612.0	62	0.36		
	1617.0	67	0.71		
	1622.0	72	1.07		
	1627.0	77	1.0		
	1632.0	82	0.71		
	1637.0	87	0.43		
	1727.0	52	-0.50		
	1732.0	57	0.36		
	1737.0	62	0.71		
	1742.0	67	1.14	0.36	
	1747.0	72	1.50	0.54	
	1752.0	77	1.38	0.64	
	1757.0	82	1.0	0.36	
	1802.0	87	0.54		
	1807.0	92	0.85		

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
19	1852.0	62	0.26		
	1857.0	67	0.78		
	1902.0	72	0.52		
	1907.0	77	0.18		
	1912.0	82	1.09		
	1947.0	52	0.25		
	1952.0	57	0.66		
	1957.0	62	1.08		
	2002.0	67	0.58		
	2007.0	72	0.50		
	2012.0	77	0.33		
	2017.0	82	0.25		
	2022.0	87	0.16		
	2027.0	92	0.58		N
20	1627.0	52	0.21		
	1632.0	57	0.55		
	1637.0	62	0.90		
	1642.0	67	1.24		
	1647.0	72	1.08		
	1652.0	77	1.31		
	1657.0	82	0.69		
	1807.0	52	0.23		N
	1812.0	57	0.46	0.25	
	1817.0	62	1.23	0.87	
	1822.0	67	1.77	0.75	
	1827.0	72	0.93		
	1832.0	77	0.43		
21	1622.0	52	0.28		
	1627.0	57	0.50		
	1632.0	62	1.0		
	1637.0	67	1.43		
	1642.0	72	1.0		
	1647.0	77	0.62		
	1652.0	82	0.85		N
	1722.0	52	0.23		N
	1727.0	57	1.0		
	1732.0	62	1.31		
	1737.0	67	0.77	0.25	
	1742.0	72	1.38	1.0	
	1747.0	77	1.0	0.60	
	1752.0	82	0.69	0.50	
	1757.0	87	0.46	0.60	

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
21	1827.0	52	0.31		
	1832.0	57	0.54		
	1837.0	62	1.23		
	1842.0	67	1.69		
	1847.0	72	1.46		
	1852.0	77	1.50		
	1857.0	82	1.25		
	1927.0	52	0.33	0.22	N
	1932.0	57	0.58	0.44	
	1937.0	62	0.50	0.44	
	1942.0	67			
	1947.0	72	1.0		
	1952.0	77	1.28	0.44	
	1957.0	82	0.93	0.67	
	2027.0	52	0.36		
	2032.0	57	0.28		
	2037.0	62	0.57		
	2042.0	67	0.36		
	2047.0	72	0.28		
22	1507.0	52	0.16		
	1512.0	57	0.33		
	1517.0	62	0.66		
	1522.0	67	1.25		
	1532.0	72	1.23		
	1537.0	77	1.38		
	1542.0	82	0.46		N
	1622.0	57	0.40		
	1627.0	62	0.60		
	1632.0	67	1.40		
	1637.0	72	1.0		
	1717.0	52	0.21		
	1722.0	57	0.21		
	1727.0	62	0.78		
	1732.0	67	1.36		
	1737.0	72	1.82		
	1742.0	77	0.82		
	1832.0	52	0.18		
	1837.0	57	0.73		
	1842.0	62	0.82		
	1847.0	67	0.90		
	1852.0	72	0.92		
	1952.0	52	0.33		
	1957.0	57	0.42	0.28	
	2002.0	62	1.08	0.57	
	2007.0	67	0.66	0.57	
	2012.0	72	0.84	0.71	
	2017.0	77	0.50	0.86	

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
23	1442.0	52	-0.31		
	1447.0	57	0.23		
	1452.0	62	0.54		
	1457.0	67	0.85		
	1502.0	72	1.38		
	1507.0	77	1.31		
	1512.0	82	1.08		
	1517.0	87	0.77		N
	1647.0	52	0.15		N
	1652.0	57	0.15		
	1657.0	62	0.62		
	1702.0	67	1.54		
	1707.0	72	1.0		
	1737.0	52	-0.16		
	1742.0	57	0.25		
	1747.0	62	0.50		
	1752.0	67	0.66		
	1757.0	72	0.54		
	1832.0	52	-0.38	0.25	N
	1837.0	57	0.92	0.42	
	1842.0	62	1.46	0.33	
	1847.0	67	1.62	0.84	
	1852.0	72	1.38		
24	1727.0	52	-0.15		N
	1732.0	57	0.69		
	1737.0	62	1.38	0.40	
	1742.0	67	1.69	0.80	
	1747.0	72	2.08	0.33	
	1752.0	77	1.31	0.55	
	1757.0	82	1.0		
	1842.0	52		0.22	
	1847.0	57		0.44	
	1852.0	62		0.33	
	1857.0	67		0.67	
	1902.0	72		0.50	
	1907.0	77		0.62	
26	1517.0	62	0.73		
	1522.0	67	0.90		
	1527.0	72	0.69		
	1532.0	77	1.23		

Date	Time (U.T.)	h_i	T_A	T_φ	Symbols
26	1802.0	52	-0.13		
	1807.0	57	0.27		
	1812.0	62	0.73		
	1817.0	67	0.53		
	1822.0	72	0.42		
	1912.0	52	-0.54		
	1917.0	57	0.31		
	1922.0	62	0.62		
	1927.0	67	1.31		
	1932.0	72	1.08		
	1937.0	77	1.38		
	1942.0	82	1.62		
	1947.0	87	0.85		
	1952.0	92	0.77		
27	1552.0	52	0.14		
	1557.0	57	0.28		
	1602.0	62	0.50		
	1607.0	67	1.0		
	1612.0	72	0.78		
	1617.0	77	1.0		
	1622.0	82	1.14		
	1627.0	87	0.71		
	1632.0	92	0.43		
28	1822.0	52	-0.55		N
	1827.0	57	0.78		N
	1832.0	62	1.11		N
	1837.0	67	0.67		N
	1842.0	72	0.89		N
	1847.0	77	0.90		N
	1852.0	82	0.82		N
	1857.0	87	0.64		N
29	1657.0	52	-0.60		N
	1702.0	57	-0.40		N
	1707.0	62	0.80	0.62	
	1712.0	67	1.0	0.37	
	1717.0	72	0.90	0.60	
	1722.0	77	0.73	0.50	
	1727.0	82	0.36	0.50	
	1732.0	87	0.27		N
	1837.0	52	0.36	0.20	S
	1842.0	57	0.73	0.40	S
	1847.0	62	1.0	0.70	S
	1852.0	67	0.90	0.40	S
	1857.0	72	0.36		S
	1902.0	77	0.36		S
	1907.0	82	0.45		S
	1912.0	87	0.36		S

Date	Time (U. T.)	h_i	T_A	T_φ	Symbols
30	1617.0	52	0.27		
	1622.0	57	0.73		
	1627.0	62	0.90		
	1632.0	67	0.90		
	1637.0	72	1.73		
	1642.0	77	1.67		
	1647.0	82	1.0		
	1652.0	87	0.33		
	1722.0	52	-0.33		
	1727.0	57	0.33		
	1732.0	62	1.0		
	1737.0	67	1.56		
	1742.0	72	2.33		
	1747.0	77	1.09		
	1752.0	82	0.73		
	1757.0	87	0.18		
	1827.0	52	-0.18		
	1832.0	57	0.36		
	1837.0	62	0.82		
	1842.0	67	1.0		
	1847.0	72	0.82		
	1852.0	77	1.46		
	1857.0	82	0.62		
	1902.0	87	0.46		
	1932.0	52	-0.38		N
	1937.0	57	0.23		N
	1942.0	62	0.54		N
	1947.0	67	0.62		N
	1952.0	72	0.62		N
	1957.0	77	0.69		N

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13. ABSTRACT

This report presents the data obtained from the measurement of phase and amplitude radio wave interaction during the period of October 1, 1965 through November 30, 1965. The work was carried out at the Ionosphere Research Laboratory, The Pennsylvania State University, (N. Lat. 40°-47', W. Long. 77°-57'), University Park, Pennsylvania, U.S.A. The present work is categorized as "miscellaneous measurements" in the decipline of "ionosphere" in the IQSY program.

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