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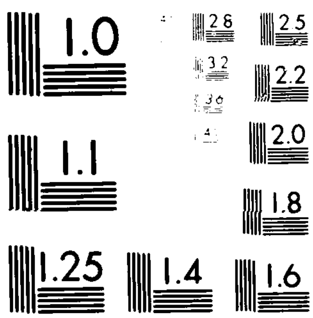
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(6) IONOSPHERIC ELECTRON CONTENT EFFECTS

ON EARTH-SPACE RADIO PROPAGATION. A REVIEW.

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(10) George H. Millman

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General Electric Company
Syracuse, New York 13221

Paper presented at the Committee on Space Research (COSPAR) Beacon Satellite Group Symposium on "Scientific and Engineering Uses of Satellite Radio Beacons", Warsaw, Poland, May 19-23, 1980

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Summary

Radio waves when traversing the ionosphere undergo various types of signal degradation due to the nonhomogeneous characteristics of the medium. In this paper, the propagational effects such as group time delay, angular bending, phase and Doppler frequency shift, rotation of the plane of polarization and dispersion resulting from the presence of ionization along earth-space transmission paths are reviewed. The phenomena are described and assessed in terms of frequencies in the VHF range and above. The various techniques for the measurement of the ionospheric ionization are briefly discussed.

Key Words:

Ionosphere
Electron Content
Index of Refraction
Time Delay
Refractive Bending
Phase Shift
Doppler Frequency Shift
Faraday Rotation
Dispersion

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SECTION I
INTRODUCTION

Prior to the advent of rockets, space vehicles and high-powered radars, the determination of the characteristics of the ionosphere, such as the distribution of electron density with height, was accomplished by vertical incidence pulse sounders. With the availability of these new techniques, the state of knowledge of the structure and composition of the ionosphere has been greatly enhanced.

Electron density profiles above the maximum ionization of the F-layer were first obtained from radio wave transmissions emanating from rockets (Jackson and Seddon, 1958; Pfister and Ulwick, 1958; Berning, 1960; Nisbet and Bowhill, 1960) and from RF probe-satellite measurements (Jackson and Kane, 1959).

The scattering of radio waves by the electron density fluctuations in the ionosphere has been a mechanism for studying the properties of the ionosphere and deriving the electron density distribution by means of a high-powered radar (Gordon, 1958; Pineo et al., 1960; Bowles, 1961; Evans and Loewenthal, 1964). The Faraday rotation phenomenon, in conjunction with incoherent scattering, has been applied to the measurement of the ionospheric electron density (Millman et al., 1964; Farley, 1966).

The first measurements of the ionospheric electron content were deduced from the radar reflections from the moon, which displayed Faraday rotation fades (Evans, 1957; Bauer and Daniels, 1959; Millman et al., 1960; Millman, 1964b). The radar measurements of differential group delay have also produced cislunar electron content (Howard, 1967).

The Faraday rotation measurement yielded electron content data along the ray path up to an altitude of approximately 1000-2000 km, while the group delay furnished ionization data along with entire earth-lunar propagation path. The acquisticn of ionospheric electron content by moon-reflected radar signals has been surveyed by Evans (1974).

Radar-pulsed transmissions reflected off the surface of a spherical satellite afforded an alternate method, which is similar to the radar-lunar technique, for measuring the electron content in the ionosphere by the Faraday effect (Millman, 1963, 1964a).

Radio waves emitted from earth's satellites and undergoing such effects as Faraday rotation and/or Doppler frequency shift, have been used to study the electron content of the ionosphere.

Utilization of the Faraday rotation method, which necessitates that the satellite-transmitted signal be linearly polarized, has been demonstrated by Garriott (1960), Blackband (1960), Yeh and Swenson (1961), Liszka (1961), Lawrence et al. (1963), Shmelovsky et al. (1963), Roger (1964), Lyon (1965), Yeon and Roelofs (1966), Checcacci (1966), Münther (1966) and Klobuchar and Whitney (1966).

The Doppler method, which requires that the satellite transmit at least two coherent harmonically related frequencies, has been employed by Ross (1960), de Mendonça (1962), Bhonsle (1966) and Millman and Anderson (1968).

The combination of the Faraday and Doppler methods, often referred to as the hybrid technique, has also been successfully applied to ionospheric electron content investigations by de Mendonça and Garriott (1962), Golton (1962), Burgess (1963) and Arendt and Soicher (1969).

The contribution of satellite beacons to studies of the structure of the ionosphere has been reviewed by Evans (1977). Davies (1980) has summarized the recent progress in satellite radio beacon investigations with emphasis on the ATS-6 radio beacon experiment. Of particular interest are the data indicating the presence of ionization in the region between 1000-2000 km and geosynchronous altitudes, i.e., plasmasphere.

The propagational effects such as group time delay, refraction, phase and Doppler frequency shift, polarization rotation and dipersion resulting from the presence of ionization along earth-space propagation paths are discussed in this paper. The phenomena are described and assessed in terms of frequencies in the very high frequency (VHF) range and above.

SECTION II

INDEX OF REFRACTION

The index of refraction in the ionosphere can be expressed by the relationship

$$n = \left[1 - \left(\frac{\omega_N}{\omega}\right)^2\right]^{1/2} = \left[1 - \frac{N_e e^2}{\epsilon_o m_e \omega^2}\right]^{1/2} \tag{2-1}$$

where ω_N is the angular plasma frequency of the medium (rad/sec), N_e is the electron density (electrons/m^3), e is the electron charge (1.6×10^{-19} C), m_e is the electron mass (9.1×10^{-31} kg), ϵ_o is the electric permittivity of free space ($10^{-9}/36\pi$ F/m) and ω ($=2\pi f$) is the angular frequency of the incident wave (rad/sec).

It is noted that the ionospheric refractive index is also a function of both the electron collision frequency and the earth's magnetic field. For frequencies on the order of 10 MHz and above, and at altitudes greater than 80 km, the effect of the collision frequency term on the index of refraction is negligible (Davies, 1965).

The refractive index, as defined by Equation (2-1), is applicable for estimating the magnitude of propagation anomalies such as group time delay, angular-refractive bending, phase-Doppler frequency shift and pulse dispersion effects.

For determining the effect of the ionosphere on linearly polarized trnasmissions, it is necessary to redefine the index of refraction in terms of magnetic field parameters. (3-2) When the magnetic field is taken into account, the refractive index for the quasi-longitudinal mode of propagation is given by (Ratcliffe, 1959)

$$n_L^2 = 1 - \omega_N^2 \left[\omega^2 \pm \omega\omega_H \cos\theta\right]^{-1} \tag{2-2}$$

where θ is the propagation angle, i.e., the angle between the magnetic field vector and the direction of propagation.

The parameter, ω_H, is the angular gyromagnetic frequency of the electrons about the earth's magnetic field and is defined by

$$\omega_H = \frac{e}{m_e} B = \frac{e}{m_e} \mu_o H \tag{2-3}$$

where B is the magnetic induction (Wb/m^2), μ_0 is the permeability of free space (4×10^{-7} H/m), and H is the magnetic field intensity (ampere-turns/m).

Equation (2-2) is valid for the condition in which the propagation angle is equal to or less than approximately 86.6° and 89.6° at 100 MHz and 400 MHz, respectively.

For quasi-transverse propagation, the index of refraction becomes

$$n_T^2 = 1 - 2\left(\frac{\omega_N}{\omega}\right)^2 \left[1 - \left(\frac{\omega_N}{\omega}\right)^2\right] \left\{2\left[1 - \left(\frac{\omega_N}{\omega}\right)^2\right] - \left(\frac{\omega_H}{\omega} \sin\theta\right)^2 \pm \left(\frac{\omega_H}{\omega} \sin^2\theta\right)^2\right\}^{-1} \tag{2-4}$$

According to Equations (2-2) and (2-4), there are two values for the refractive index. The positive sign is associated with the ordinary wave while the negative with the extra-ordinary wave.

SECTION III

TIME DELAY

Time delays or range errors are always inherent in the measurement of positional data of space vehicles by radio waves. This is due to the fact that the velocity of eletromagnetic propagation in the ionosphere is slightly less than the free space velocity. In other words, the presence of the ionosphere introduces an increase in the effective group path length relative to free space.

The ionospheric travel time for a radio wave signal transmitted from a satellite to the ground (or vice versa) is represented by the integral

$$t = \int_0^s \frac{1}{V_g}\, ds = \frac{1}{c}\int_0^s \frac{1}{n}\, ds \approx \frac{s}{c} + \frac{e^2}{8\pi^2 c\epsilon_o m_e f^2}\int_0^s N_e\, ds \qquad (3\text{-}1)$$

where V_g is the group velocity of the signal, c is the free space velocity (3×10^8 m/sec) and ds is the differential distance along the transmission path. The first term on the right side of Equation (3-1) is the transmit time of the signal in free space while the second term is the additional time delay introduced by the ionosphere.

It follows from Equation (3-1) that, for frequencies in the VHF band and above, the increase in range (in meters), i.e., range error, due to the ionosphere, can be defined by

$$\Delta R = \frac{e^2}{8\pi^2 \epsilon_o m_e f^2}\int_0^s N_e\, ds = \frac{e^2}{8\pi^2 \epsilon_o m_e f^2}\int_0^h N_e \sec\psi\, dh$$

where ψ is the angle between the ray path and the zenith and dh is the differential distance in the vertical direction. The parameter, $\sec\psi$, is the obliquity factor accounting for the slant path geometry.

Figure 3-1 is a plot of the range error and the ionospheric time delay for a one-way transmission path as a function of frequency and electron content. At 100 MHz, the time delay is 13.43 μsec for an electron content of 10^{18} electrons/m^2. The range error corresponding to this delay is 4029.6 m.

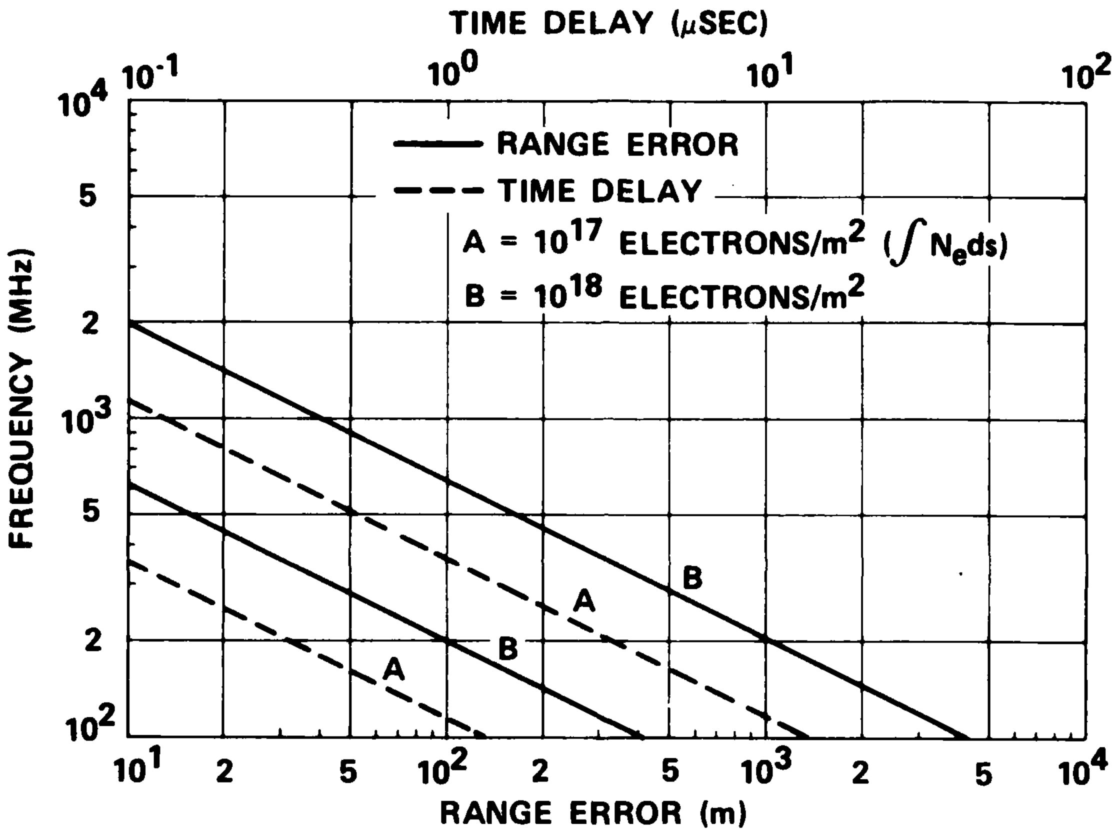

Figure 3-1. Ionospheric Range Error and Time Delay for a One-Way Path

It is of interest to note that, in general, 50% of the range error and time delay takes place below an altitude of approximately 300 km irrespective of the elevation angle (Millman, 1967).

In Figure 3-2, the ionospheric range error is plotted as a function of the elevation angle. It is seen that the error is relatively independent of elevation angle below approximately 4° and that the error along the horizon is on the order of 2.75 times larger than that at 60° elevation angle.

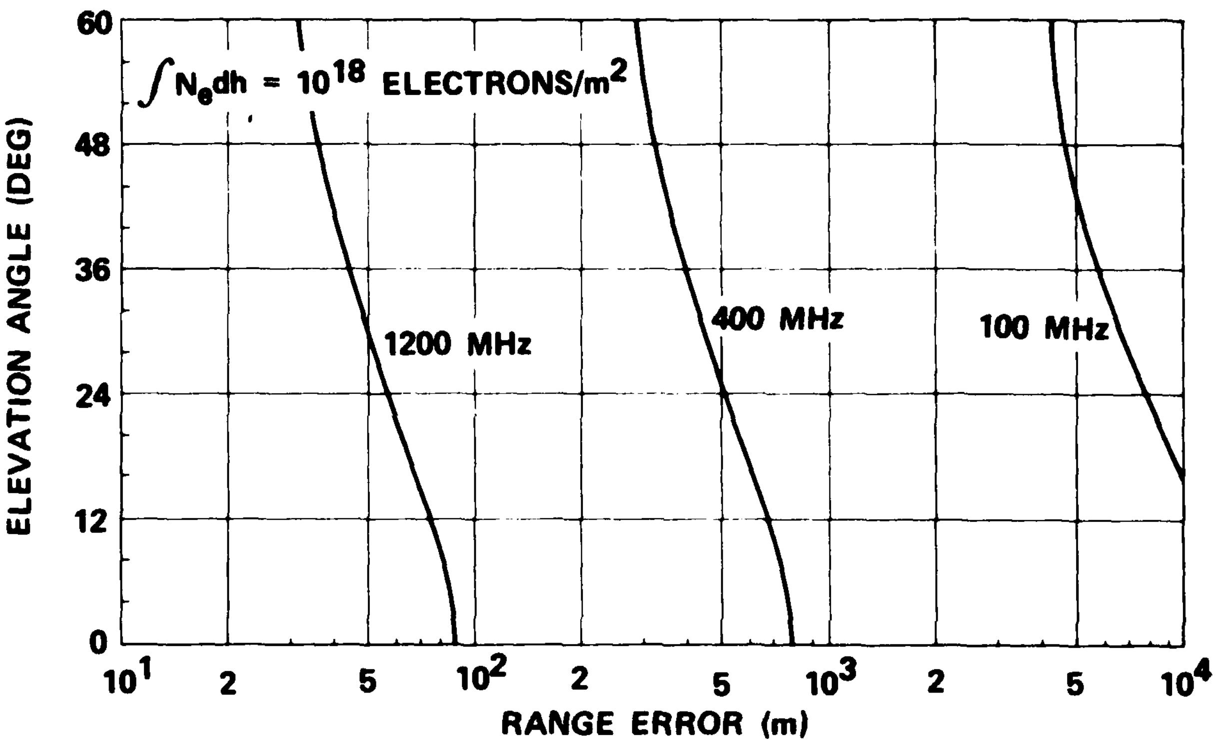

Figure 3-2. Ionospheric Range Error as a Function of Elevation Angle

SECTION IV

REFRACTIVE BENDING

When radio waves traverse the ionosphere, they undergo a change in direction or refractive bending. This phenomenon, which results from the nonhomogeneous characteristics of the medium, introduces an error in the measurement of the angular position of a space vehicle.

The elevation angle error can be expressed in terms of the range error by the function (Millman and Reinsmith, 1974)

$$\Delta E = \frac{(R + r_o \sin E_o)\, r_o \cos E_o}{[h_i (2r_o + h_i) + (r_o \sin E_o)^2]} \quad \frac{\Delta R}{R} \tag{4-1}$$

where R is the range to the satellite, r_o is the radius of the earth (6371 km), E_o is the apparent elevation angle of the satellite and h_i is the altitude at which the medium electron content along the ray path occurs. The altitude applicable to h_i is, for the most part, between approximately 300 and 450 km.

For high elevation angles, i.e., $r_o \sin E_o > R$, the angular error simplifies to

$$\Delta E \approx \cot E_o \frac{\Delta R}{R} \tag{4-2}$$

For low elevation angles and long ranges, i.e., $R > r_o \sin E_o$, Equation (4-1) reduces to

$$\Delta E \approx \frac{\cos E_o}{2h_i} \Delta R \tag{4-3}$$

The ionospheric refraction angle error at 100 and 400 MHz is shown in Figure 4-1 as a function of the apparent elevation angle. The calculations are based on a satellite located at an altitude of 1000 km. An interesting feature of the plot is that, at a constant altitude, the error increases with elevation angle, attaining a maximum value at approximately 4°. Similar results were obtained for ionospheric ionization which followed a Chapman model (Millman, 1967).

According to Figure 4-1, for a vertical electron content of 10^{18} electrons/m^2 and 100 MHz frequency, the refraction angle error at 4° is approximately 18.6 mrad. The error decreases to 2.4 mrad at 60° elevation angle.

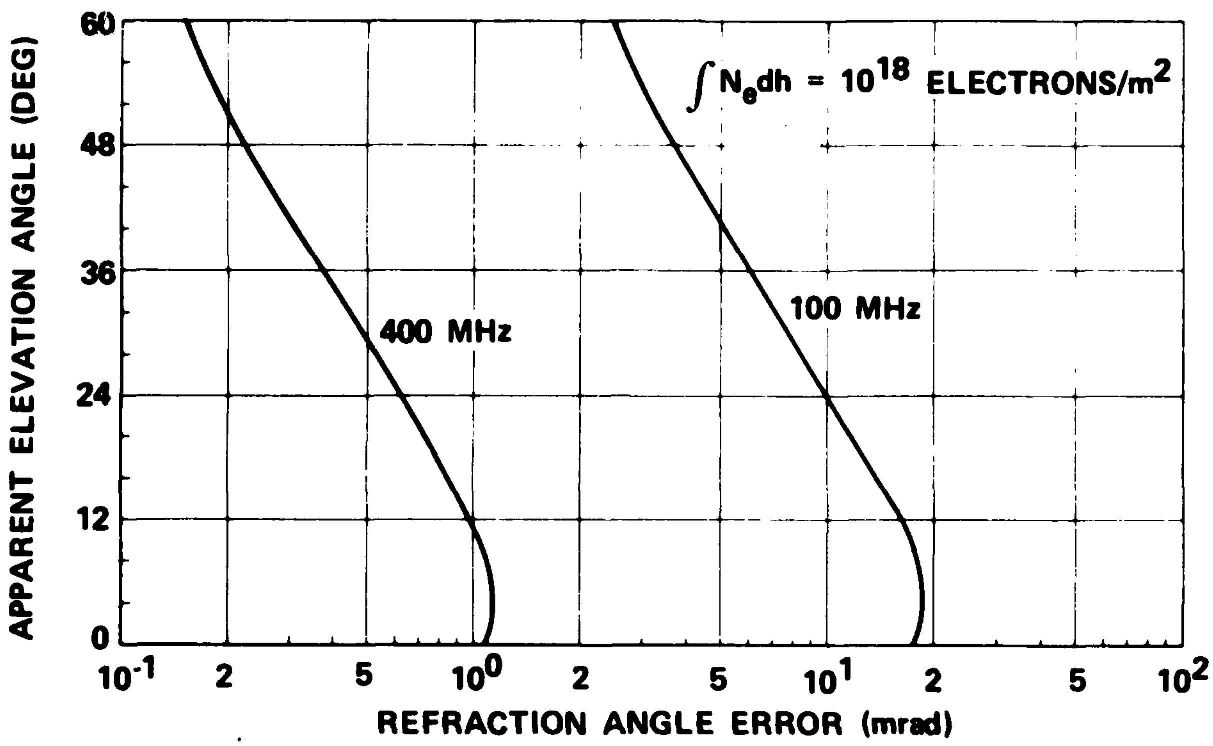

Figure 4-1. Ionospheric Refraction Angle Error as a Function of Apparent Elevation Angle

SECTION V

PHASE AND DOPPLER FREQUENCY SHIFT

The phase delay experienced by radio wave transmissions in the ionosphere on a one-way earth-space propagation path is given by

$$\phi = \frac{\omega}{c} \int_0^s n \, ds \tag{5-1}$$

On substituting the definition of the refractive index, Equation (2-1), in this expression, the ionosphere phase term can be written, as a first approximation, as

$$\phi_i = \frac{\omega}{c} s - \frac{e^2}{4\pi c \epsilon_o m_e f} \int_0^s N_e \, ds \tag{5-2}$$

where the first term is the free space effect and the second is the ionospheric contribution It is noted that the higher order terms have been neglected.

In the case of a geostationary satellite radiating to earth, changes in phase can occur as a result of the ionization variation along the path stemming from the diurnal effects and from the presence of travelling ionospheric disturbances (TIDs). A TID is a large-scale, electron-density perturbation in the F-region of the ionosphere having a horizontal component of velocity on the order of 100-200 m/sec. Typical values of the wavelengths of the perturbations, i.e., spatial dimensions, range from 150 to 1000 km. A TID could impart a modulation as large as 5% on the ambient electron content.

TIDs are hypothesized to be compressions and rarefractions of electron density caused by the passage of internal atmospheric gravity waves. Assuming a sinusoidal electron density perturbation, the one-way ionospheric phase variation due to a TID can be described by the function

$$\phi(t) = \frac{e^2 M}{4\pi c \epsilon_o m_e f} \cos\left(\frac{2\pi v t}{L}\right) \int_0^s N_e \, ds \tag{5-3}$$

where M is the modulation factor, v is the horizontal velocity of the TID and L is the TID dimension. It is noted that the ratio, L/v, specifies the period of the TID. It is seen that the ionospheric phase delay is directly proportional to the electron content along the transmission path and inversely proportional to the frequency.

The maximum phase change resulting from a TID is presented in Figure 5-1 as a function of frequency. The calculations are based on an ambient electron content of 10^{18} electrons/m^2 and on a TID with a horizontal velocity of 200 m/sec, wavelength of 150 km and modulation of 1, 2 and 4%. The phase change applies to the time interval of 375 sec which is one-half the period of the TID. It is found that, at 100 MHz frequency, the phase change is 337.58 rad. It follows that rate of phase change $(\Delta\phi/\Delta t)$ evaluates to 0.90 rad/sec.

The frequency of a radio signal emitted from a space vehicle and received on the earth experiences an apparent shift. This phenomenon which is referred to as the Doppler effect occurs because of the relative motion between the transmission source and the stationary receiver terminal.

The nonrelativistic Doppler frequency shift, f_d, in the ionosphere can be defined by the relationship

$$f_d = -\frac{f}{c}\frac{dP}{dt} = -\frac{f}{c}\frac{d}{dt}\int_0^s n\, ds = -\frac{1}{2\pi}\frac{d\phi}{dt} \qquad (5\text{-}4)$$

where P is the phase path length.

Substituting Equation (5-2) in Equation (5-4), there results

$$f_d = -\frac{f}{c}\frac{ds}{dt} + \frac{e^2}{8\pi^2 c\, \epsilon_o\, m_e\, f}\frac{d}{dt}\int_0^s N_e\, ds \qquad (5\text{-}5)$$

The first term in Equation (5-5) describes the Doppler frequency shift for an object moving in free space. The second term basically defines the frequency shift imposed by the ionosphere. It is seen that the ionosphere Doppler shift is a function of the time derivative of the electron content along the propagation path to the object and is inversely proportional to the frequency.

Estimates of the Doppler frequency shift due to a TID are given in Figure 5-2. The data which are based on the TID parameters used in calculation of Figure 5-1 indicate that, at a frequency of 100 MHz, a Doppler frequency shift of 0.14 Hz could occur.

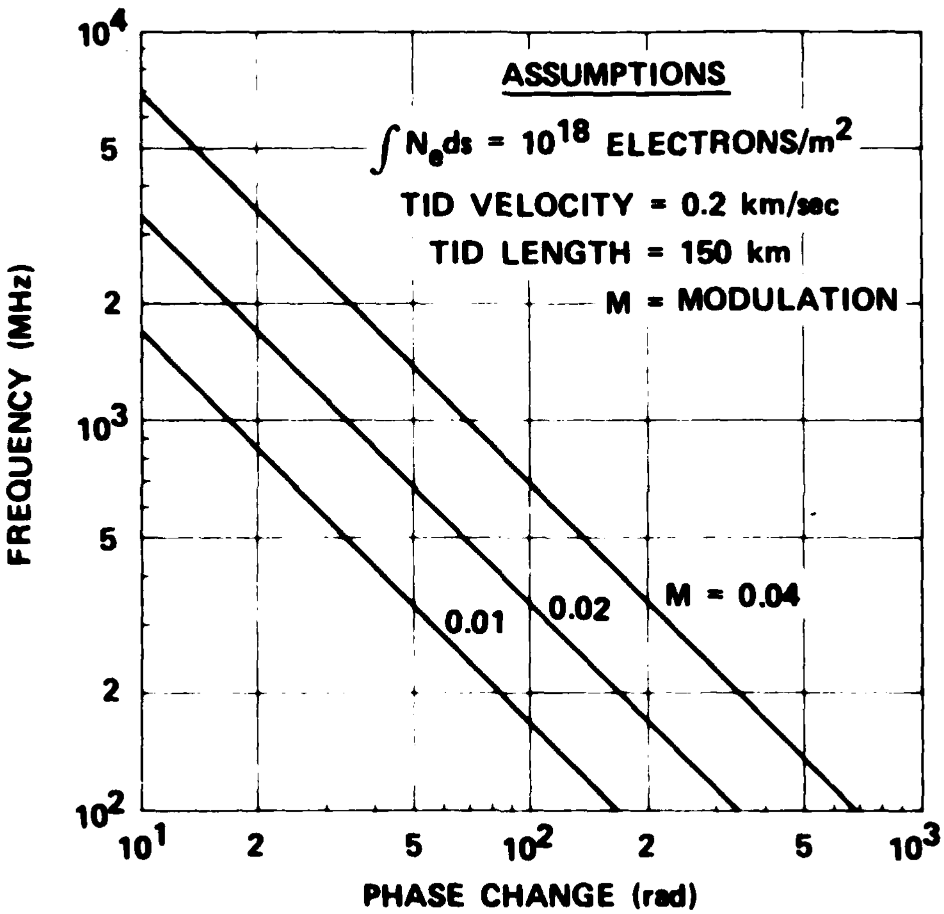

Figure 5-1. Maximum Phase Change Due to a Travelling Ionospheric Disturbance

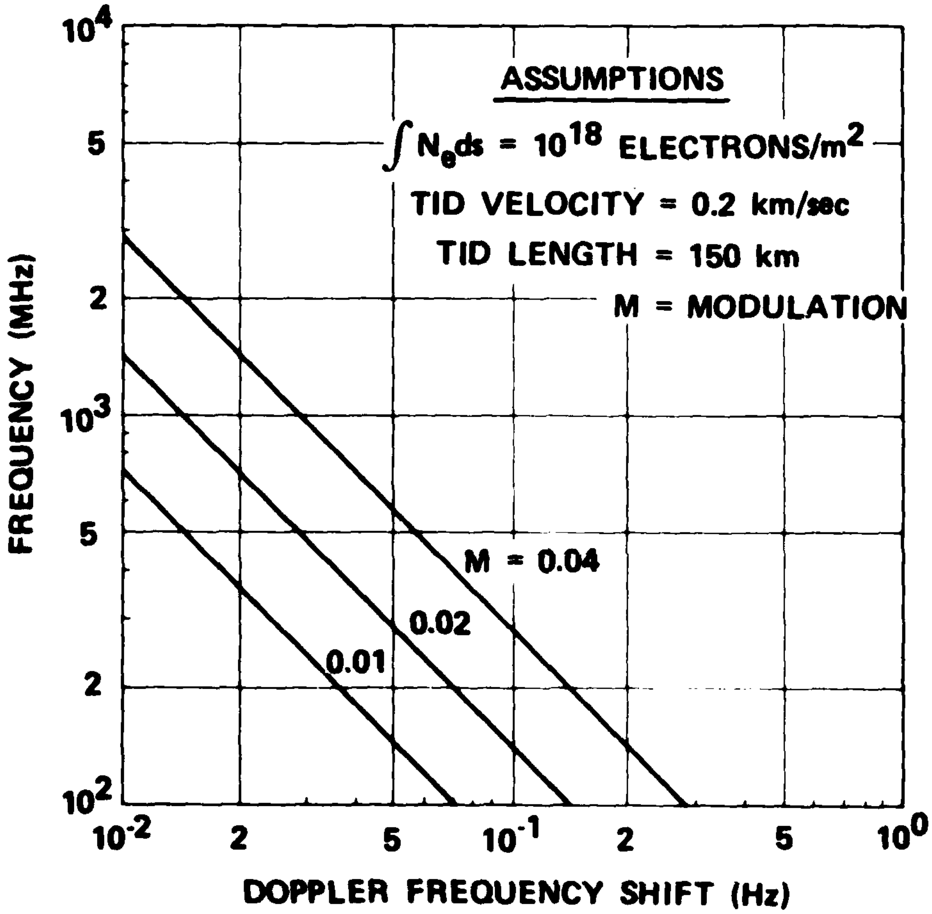

Figure 5-2. Doppler Frequency Shift Due to a Travelling Ionospheric Disturbance

SECTION VI

FARADAY POLARIZATION ROTATION

A linearly polarized wave when propagating through the ionosphere separates into two components both in the general case elliptically polarized with opposite senses of rotation. However, for frequencies in the VHF range and above, the waves are circularly polarized. Since the two waves travel with different velocities of propagation, their phase relationships are continuously being altered. On emerging from the ionosphere, the waves recombine to form a linearly polarized wave whose plane of polarization has been rotated with respect to that of the incident wave. This phenomenon is the result of the interaction of the electromagnetic wave with the electrons in the presence of the earth's magnetic field.

The amount of angular rotation, Ω (rad), experienced by a linearly polarized wave transversing a one-way path in the ionosphere can be represented by the function (Millman, 1974)

$$\Omega = \frac{\omega}{2c} \int_0^s \Delta n \; ds \tag{6-1}$$

where Δn is the difference in the refractive index between the ordinary and the extraordinary wave.

It can be readily shown that, on expanding Equation (2-2) by the binomial theorem and neglecting higher order terms, the refractive index difference for the quasi-longitudinal case simplifies to

$$\Delta n = \frac{\omega_N^2 \, \omega_H}{\omega^3} \cos \theta \tag{6-2}$$

It follows from Equations (2-1) and (2-3) that the angular polarization rotation for a one-way quasi-longitudinal path can be expressed by

$$\Omega = \frac{e^3}{8\pi^2 c \, \epsilon_o \, m_e^2 \, f^2} \int_0^s N_e \, B \cos \theta \; ds \tag{6-3}$$

It is seen that the angular rotation is inversely proportional to the frequency squared and directly proportional to the integrated product of the electron density and the component of the earth's magnetic field in the direction of propagation.

For the quasi-transverse mode of propagation, the difference in the refractive indices can be determined from Equation (2-4). It can be shown that, for this case,

$$\Delta n = \frac{\omega_N^2 \, \omega_H^2}{2\omega^4} \sin^2\theta \tag{6-4}$$

Thus, the angular polarization rotation for quasi-transverse propagation becomes

$$\Omega = \frac{e^4}{32\pi^3 \, c \, \epsilon_o \, m_e^3 \, f^3} \int_0^s N_e \, B^2 \sin^2\theta \; ds \tag{6-5}$$

It is evident that, for the quasi-transverse propagation mode, the rotation is inversely proportional to the frequency cubed and directly proportional to the integrated product of the electron density along the propagation path and the square of the component of the earth's magnetic field perpendicular to the direction of propagation.

According to Equations (6-2) and (6-4), the angular rotation for the longitudinal mode is greater than that for the transverse mode by the factor of $(2\omega/\omega_H)$ which evaluates to 142.9 at a frequency of 100 MHz.

Figure 6-1 is a plot of the rotation encountered in longitudinal and transverse propagation on a one-way path. The calculations are based on $B = 0.5$ G (0.5×10^{-4} Wb/m^2), electron content of 10^{17} and 10^{18} electrons/m^2 and $\theta = 0°$ and $\theta = 90°$ for the longitudinal and transverse mode, respectively. It is seen that the maximum polarization rotation could be on the order of 0.9 radian at a frequency of 1200 MHz and 8 radians at 400 MHz.

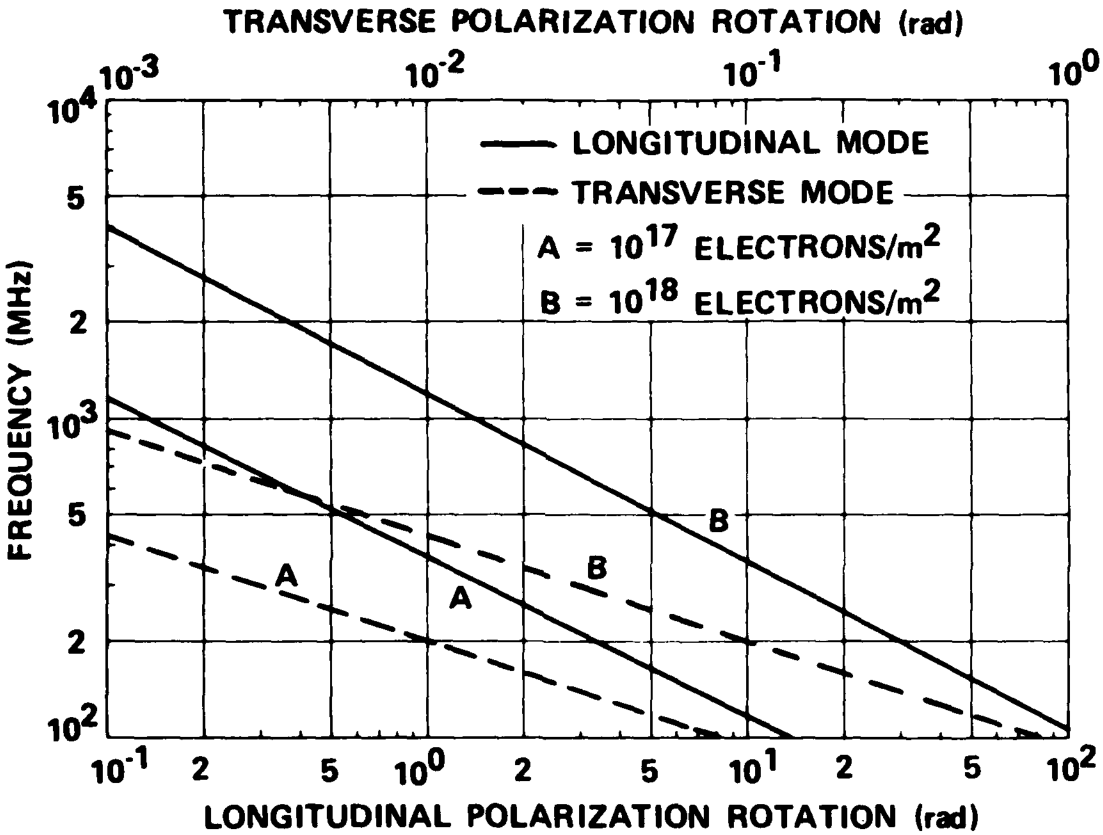

Figure 6-1. Faraday Polarization Rotation

SECTION VII

DISPERSION

Because the ionosphere is a dispersive medium, i.e., the index of refraction is a function of frequency, the frequency components in the spectrum of a pulsed electromagnetic wave propagating through the medium undergo different phase shifts. The phenomenon can cause pulse distortion, the magnitude of the effect being dependent upon the ionospheric conditions and the system parameters, such as the signal bandwidth and the carrier frequency.

The effects of a dispersive medium on electromagnetic signals have been theoretically investigated by Budden (1961), Ginzburg (1961), Knop (1964), Wait (1964), Bek (1966), Kozaki and Mushiake (1969) and Millman et al., (1972). Dispersion effects on frequency-modulated (FM) signals have been examined by Millman and Bell (1971), Millman et al.; (1972), El-Khamy and McIntosh (1973) and Brookner (1978).

It can be shown from Equation (3-1) that, for a one-way transmission path, the difference in the time delay between the two frequencies at opposite ends of the spectrum of a pulse is given by

$$\Delta t = \frac{e^2 \Delta f}{4\pi^2 c \epsilon_o m_e f^3} \int_0^s N_e \, ds \qquad (7\text{-}1)$$

where Δf is the bandwidth associated with the pulse length τ ($\Delta f = 1/\tau$).

An estimate of the difference in the time delay between the lower and upper frequencies of the spectrum of a pulse transmitted through the ionosphere is presented in Figure 7-1. Assuming that the integrated electron density along the path is 10^{18} electrons/m^2, it is seen that, at a frequency of 1200 MHz, the time delay difference encountered by a pulse of 0.1 -μsec width (10 MHz bandwidth) is approximately 1.55 x 10^{-3} μsec. If the signal spectral bandwidth is increased to 100 MHz (τ = 0.01 μsec), the difference in the time delay becomes 1.55 x 10^{-2} μsec, which is slightly greater than the duration of the transmitted pulse.

The degradation induced by the dispersive characteristics of the ionosphere on a Gaussian-shaped pulse can be described by the changes in the amplitude and pulse length of the transmitted signal. For a one-way transionospheric path, the resulting signal amplitudes, A_r, and pulse length, σ_r, are of the form (Bek, 1966; Millman and Bell, 1971)

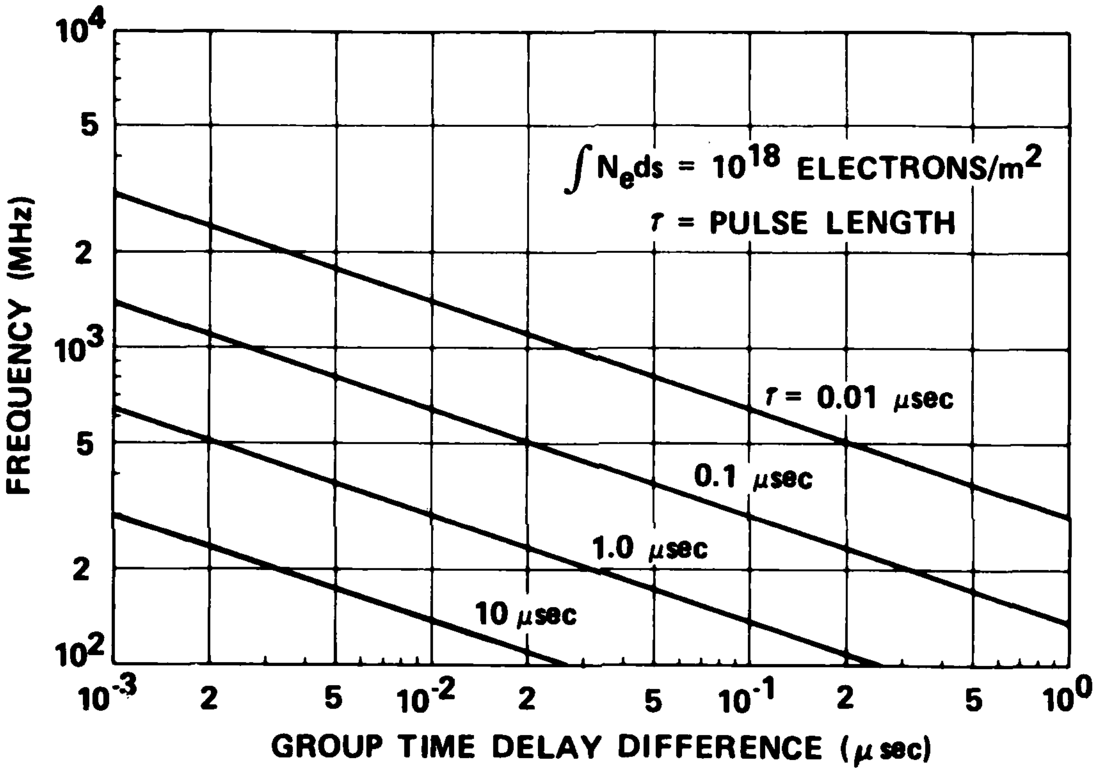

Figure 7-1. Time Delay Difference Between Lower and Upper Frequencies of Spectrum of Pulse Transmitted through Ionosphere, One-Way Transmission Path

$$A_r = A_o \frac{1}{\left\{1 + [\Phi''(\omega)/\sigma^2]^2\right\}^{1/4}} \tag{7-2}$$

$$\sigma_r = \sigma \left\{1 + [\Phi''(\omega)/\sigma^2]^2\right\}^{1/2} \tag{7-3}$$

where A_o is the transmitted signal amplitude and σ is the standard deviation of the Gaussian distribution. For convenience, the pulse length, τ, is defined in terms of the standard deviation as $\tau = 4\sigma$. The primes signify the derivative of $\Phi(\omega)$, the phase shift, with respect to ω, the angular carrier frequency.

If follows from Equation (5-2) that the 2nd derivation of $\Phi(\omega)$ becomes

$$\Phi''(\omega) = -\frac{e^2}{8\pi^3 c \epsilon_o m_e f^3} \int_0^s N_e \, ds \tag{7-4}$$

A *Gaussian pulse traversing the* ionosphere will also experience a frequency modulation, m, of the form

$$m = \frac{\Phi''(\omega)/\sigma^4}{1 + [\Phi''(\omega)/\sigma^2]^2} \tag{7-5}$$

where $m = (\Delta\omega/\tau)$ and $\Delta\omega$ is the imposed angular signal bandwidth.

According to Equations (7-2), (7-3), and (7-5), when a Gaussian waveform is transmitted through a dispersive medium, the emergent signal has the following characteristics: the amplitude decreases, the pulse length increases and a linear frequency modulation is induced.

The effects of ionospheric dispersion are illustrated in Figures 7-2 and 7-3 which are plots of the normalized amplitude and pulse length, respectively, as a function of frequency. It is seen in Figure 7-2 that, for an electron content of 10^{18} electrons/m^2 and signal bandwidths of 5 and 10 percent, the decrease in amplitude at 400 MHz could be as high as 6.4 dB and 12.3 dB, respectively, while, at 5000 MHz, the decay could be on the order of 0.2 dB and 2.3 dB, respectively.

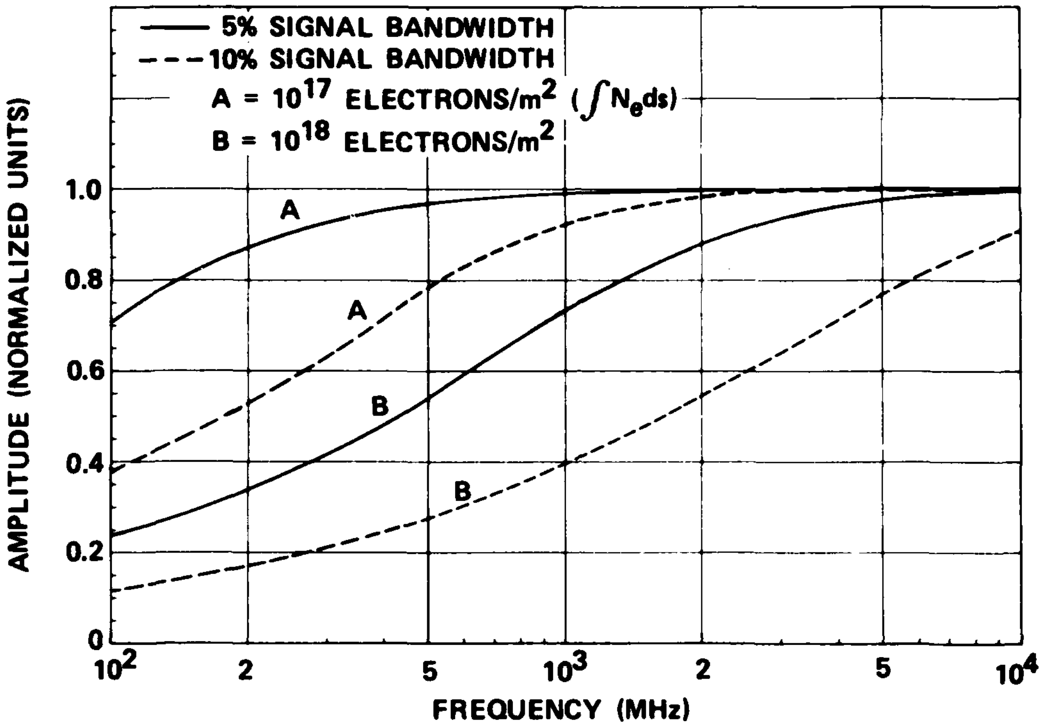

Figure 7-2. Amplitude Modification of a Gaussian Pulse Traversing the Ionosphere

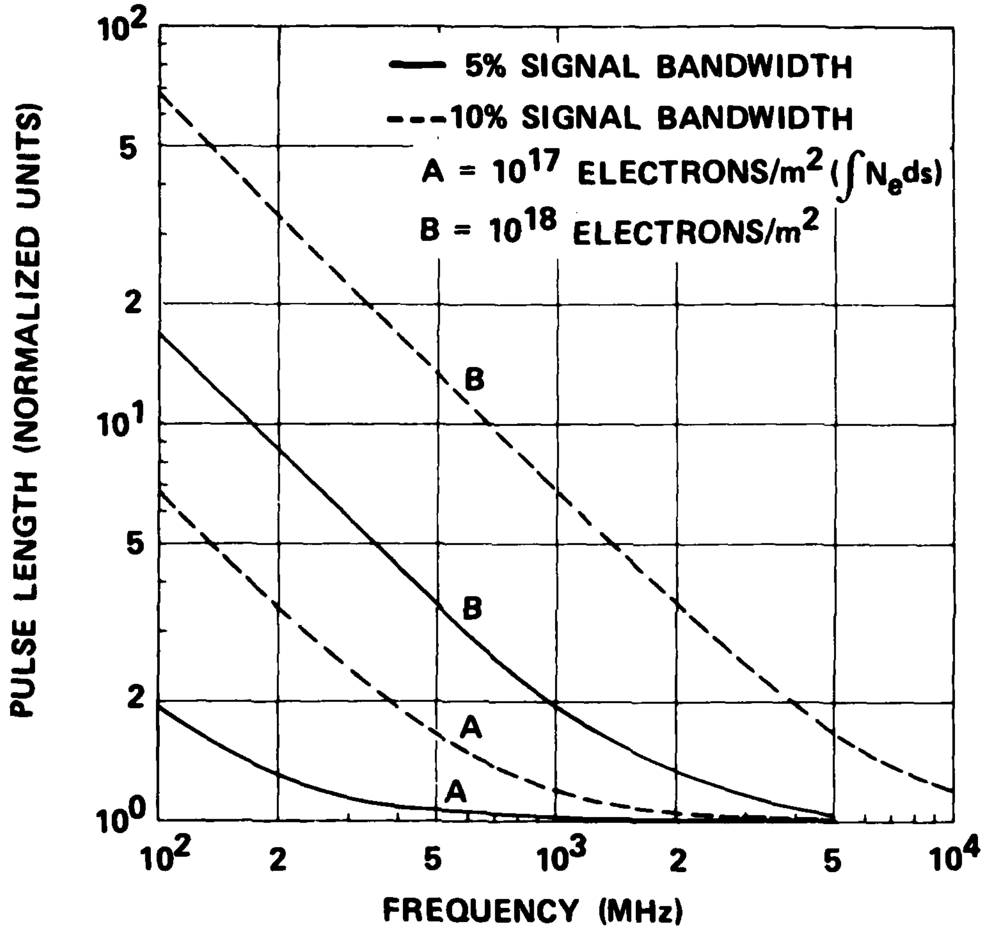

Figure 7-3. Pulse Length Modification of a Gaussian Pulse Traversing the Ionosphere

With regard to Figure 7-3, the pulse length increases at 400 MHz by a factor of approximately 4 and 17 at a bandwidth of 5 and 10%, respectively. At 5000 MHz, the increase in the pulse length is only a factor of about 0.05 and 1.7, respectively.

A Gaussian pulse transmitted through the ionosphere will also experience a frequency modulation. According to Figure 7-4, for a given frequency, an increase in the electron content or in the signal bandwidth results in an increase in depth of frequency modulation.

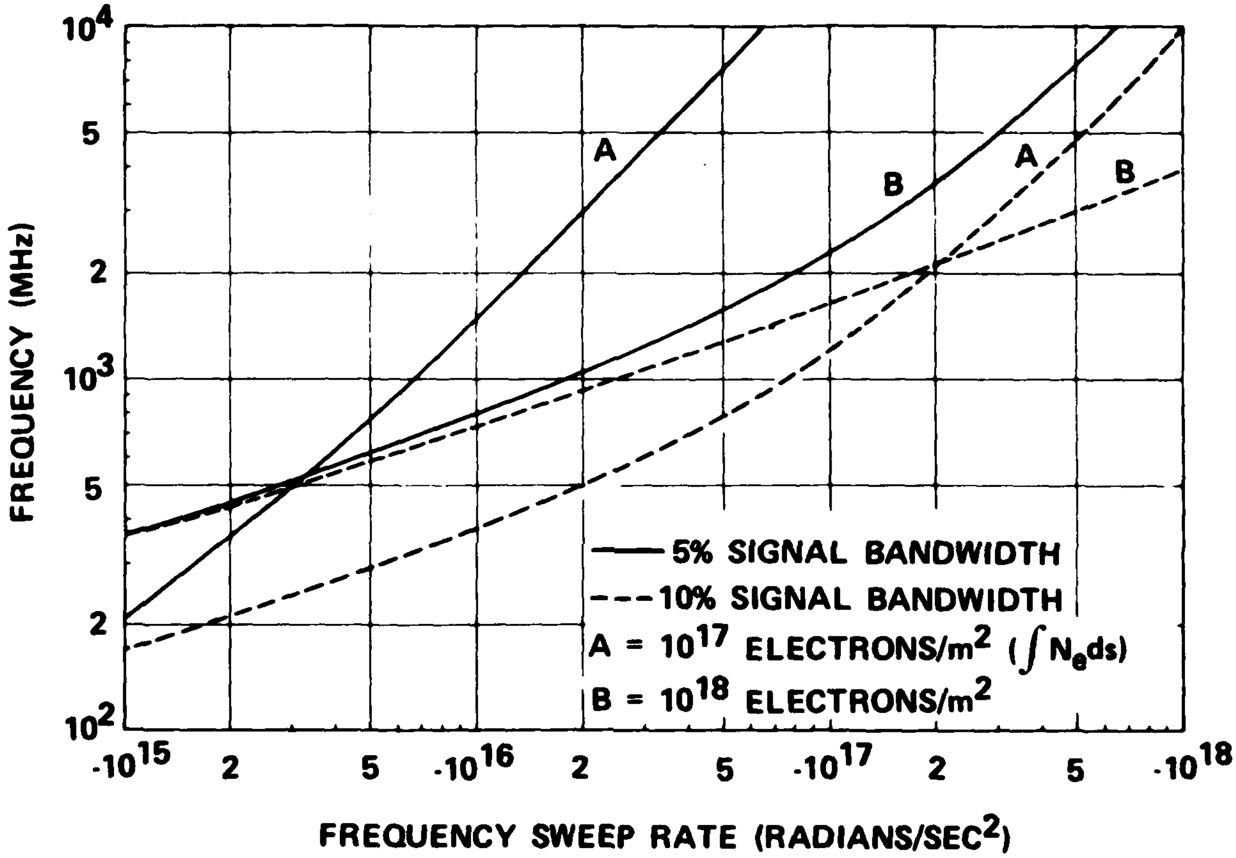

Figure 7-4. Frequency Modulation Induced in a Gaussian Pulse Traversing the Ionosphere

SECTION VIII

CONCLUSIONS

The estimates of the magnitude of the ionospheric propagation effects such as time delay, refraction, phase and Doppler frequency shift, polarization rotation and dispersion discussed in this paper are representative of normal ionospheric conditions. Because of the dynamic characteristics of the ionosphere, in addition to the ionization being dependent on such parameters as solar and geomagnetic activity, season and time-of-day, the electron content along a ray path cannot be accurately specified.

Various techniques could be applied for ionospheric correction adjustment such as an electron content prediction model, i.e., algorithm, vertical incidence ionospheric soundings and the monitoring of the transmissions of radio beacon satellities. It is possible that a reduction in error correction and in the signal degradation on the order of 50 to 75% could be achieved. An evaluation of the techniques which could be employed in the reduction of the ionospheric effects are beyond the scope of this paper. Reference is made to publications on this subject by Bell et al., (1969), Klobuchar and Allen (1970), Klobuchar (1975) and Soicher (1979).

SECTION IX

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