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RFI EMITTER LOCATION TECHNIQUES

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B. L. J. RAO

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B. L. J. Rao
Communications and Navigation Division

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ABSTRACT

This document discusses the possibility of using doppler techniques for determining the location of ground based emitters causing radio frequency interference (RFI) at the low orbiting satellites. An error analysis indicates that it is possible to find the emitter location within an error range of 2 n. mi. The parameters which determine the required satellite receiver characteristic are discussed briefly along with the non-real time signal processing which may be used in obtaining the doppler curve. Finally, the required characteristics of the satellite antenna are analyzed.

CONTENTS

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INTRODUCTION

Many attempts have been made to measure the spectrum utilization with mobile or airborne receivers.[1,2] This method is slow and not economically feasible on a globe scale. Recently there is a growing interest in finding RFI at orbital altitudes.[3,4] There is very little experimental work reported to date and no attempts were made so far to find the geographical location of different RFI sources. Recently NASA/GSFC proposed an RFI experiment to determine the frequency, type of modulation and the location of the ground based RFI sources, which may interfere with the low orbiting satellites. The purpose of this document is to discuss the feasibility of using doppler techniques in determining the location of the ground based RFI emitters. The doppler measurements are assumed to be made at the low orbiting satellite using a suitable receiver. The frequency bands of interest are 180-174 MHz, 240-478 MHz and 1535-1665 MHz.

It is well known that the "doppler effect" enables a satellite to locate C. W. transmitters on the surface of the earth.[5,6] The same method with some modifications could be used to find the RFI emitter location. Several other methods of radio location are considered,[7,8] but rejected for different reasons.

Two methods of using the "doppler effect" in determining the emitter location are discussed first. Then, a brief discussion on error analysis is included. It is concluded that it is possible to find the emitter location within an error range of 2 n. mi. using doppler effect. The parameters which determine the satellite receiver characteristics are discussed briefly along with the now-real time signal processing, which may be used in obtaining the doppler curve. Finally, the satellite antenna requirements are briefly analyzed.

DOPPLER TECHNIQUES

The relative motion of the satellite causes the frequency received by the satellite to differ from the transmitted frequency from the earth. The bases for the position estimation are the unique relationships existing between successive RFI frequency measurements at the satellite and the location of the source relative to the satellite. The frequency measurement may be considered to determine the complete doppler curves of a source during one or more passes. From another viewpoint, the frequency measurements can be used to spatially locate and orient a number of geometric surfaces upon which the source is known to lie.

When the satellite orbit is known, a measurement of the doppler curve in the vicinity of zero doppler shift allows a determination of the time and the line of sight range to the transmitter. Consequently the position of the transmitter could be determined relative to the satellite. This principle is well known in navigation for several years.[5,9] It is recognized recently[5,10] that there is a tremendous redundancy in the information contained in the shape of the doppler curve. The position of the transmitter can be determined not only from the time and slope of the curve at the point of maximum slope, but also from a comparison of the doppler shift at any two points on the curve. Thus in principle, each pair of data points on the doppler curve determines the transmitter location and each of these determinations are statistically independent (except for some bias errors due to atmospheric refraction, which will be discussed later). This observation could be used to reduce the effect of random errors in measuring the doppler curve.

The mathematical relationships between the doppler frequency, range rate between the satellite and source, and the source location geometry are discussed below.

The phase angle of the received signal at the satellite is given by:

$$\phi(t) = \omega_o t + \vec{R}_{SE} \cdot \frac{2\pi}{\lambda o} + \phi_o \tag{1}$$

where $\omega_o = 2\pi f_o$, f_o being the transmitted frequency

$\vec{R}_{SE} = \vec{R}_S - \vec{R}_E$ is the range between satellite and the source

$\vec{R}_S = (x_S, y_S, z_S)$ is the position vector of the satellite

$\vec{R}_E = (x_E, y_E, z_E)$ is the position vector of the emitter (source)

ϕ_o = A constant phase angle

The instantaneous frequency of reception is given by:

$$f(t) = \frac{1}{2\pi}\frac{d\phi}{dt} = f_o + \frac{1}{\lambda o}\frac{d\vec{R}_{SE}}{dt}$$

Therefore

$$f(t) - f_o = \frac{1}{\lambda o}\frac{d\vec{R}_{SE}}{dt} \tag{2}$$

Since $f(t) - f_o$ represents the doppler frequency and $d/dt\vec{R}_{SE}$ is the range rate, equation (2) gives the relation between these two. So, knowing the doppler frequency, the range rate is also known.

The range rate could also be written as follows:

$$V_R = \frac{d}{dt}(\vec{R}_S - \vec{R}_E) = \frac{(\vec{R}_S - \vec{R}_E) \cdot \vec{V}_S}{|\vec{R}_S - \vec{R}_E|} \tag{3}$$

where V_R is the measured range rate
$\vec{V}_S$ is the velocity vector of the satellite
$\vec{R}_S$ and $\vec{V}_S$ are assumed to be known

So only unknown in equation (3) is $\vec{R}_E$. If we know the longitude and the latitude of the emitter, we know $\vec{R}_E$. So there are only two parameters to be determined. In principle, these unknowns can be determined by measuring range rate at two satellite locations. However this is possible only if the emitter frequency f_o is known. Since f_o may not be known exactly (but assumed to be a constant during the measurement period), one could assume a constant bias error in the range rate measurement. If the bias is in the units of velocity say V_D, then the equation (3) becomes

$$\frac{\vec{R}_{SE} \cdot \vec{V}_S}{|R_{SE}|} + V_D - V_R = o \tag{4}$$

From at least three measurements of doppler (or V_R) at three different satellite locations, the equation (4) could be solved for V_D and the two other unknown parameters of the source (longitude and latitude).

Therefore, in principle just three measurements of the doppler frequency at three satellite locations will determine the source location. Knowing the complete or partial doppler curve over one complete pass contains large amount of redundancy. This redundancy may be used to reduce the random errors introduced by noise or other statistical errors by proper signal processing. More details on the error analysis will be given in a later section. The advantage of this method lies in the fact that the frequency of transmission need not be known precisely, only a partial doppler curve need be known and the large amount of redundancy which exists even in partial doppler curve could be used in reducing random errors.

When a complete doppler curve is available or when the maximum rate of change of doppler is known, a much simpler approach could be used in determining the source location. The procedure is to record the doppler signal as the satellite passes nearby the source. At the point of closest approach (R_o), the rate of change of frequency with time is a maximum and is related to R_o as follows:[9]

$$R_o = \frac{V_S}{\lambda_o(df_d/dt)\max} \tag{5}$$

where V_S is the satellite velocity

λ_o = transmitted wavelength

f_d = observed doppler frequency

R_o = point of closest approach.

In equation (5) V_S is assumed known, λ_o corresponds to the received signal frequency at the time at which maximum doppler rate occurs. So, the accurate measurement of this frequency is a prerequisite for this method. Also, the unknown source location imposes the condition that the complete doppler curve be known so that the time at which maximum doppler rate takes place will be included in that curve. Another disadvantage of this method is that the large amount of redundancy which exists in the doppler curve is not used. Consequently, the method discussed earlier gives better accuracy. The method discussed later in this section uses simple signal processing.

ERROR ANALYSIS

The probable causes of errors in obtaining doppler curve are enumerated below.

(1) Random noise
(2) Ionospheric refraction
(3) Frequency drifts of the source oscillator
(4) Frequency drifts of the satellite oscillator

It was mentioned earlier that by using the large amount of redundancy which exists in the complete doppler curve, it is possible to reduce the errors introduced by the random noise or any other random errors introduced into the doppler curve. In general this error is comparatively negligible with other errors.

The errors introduced by the ionospheric refraction decreases with the increase in frequency.[5] At the lowest frequency of interest (140 MHz) the ionospheric refraction contributes about 5 Hz to the doppler curve. The corresponding error in source location is about 1 n. mi.[6] For higher frequency bands the refraction errors are negligible.

When the source transmitted frequencies drift with time, they appear in the doppler curve and introduce errors in source location. However, if one assumes that the transmitter frequency remains constant during a single pass, it was explained earlier, that it is possible to correct for long term instability. This is done by assuming the source frequency as an unknown parameter, and solving for three unknowns (frequency, latitude and longitude of the source) using three doppler measurements, as explained in detail in the previous section.

The above remarks concerning the source frequency drifts will also apply to satellite oscillator drifts. Since, oscillators with good short term stability are available, there seems to be no problem in this respect.

RECEIVER REQUIREMENTS

Receiver requirements depend on the type of signal received (AM or FM etc.), signal bandwidth, the amount of doppler and the rate of change of doppler frequency. It also depends on any signal processing contemplated at the satellite or on the ground. Since the amount of doppler expected will influence the required receiver bandwidth, and the rate of change of doppler will influence the receiver capability of tracking a particular source, these two parameters are calculated for a typical low orbiting satellite (ITOS).

Maximum Doppler Frequency Expected:

The required receiver bandwidth depends not only on the signal bandwidth but also on the expected maximum doppler frequency. The maximum doppler frequency is given by:

$$f_{d\,max} = \pm f_o \frac{V_S}{C} \frac{R}{R+h} \tag{6}$$

where $f_{d\,max}$ = maximum doppler frequency
f_o = carrier frequency of the source
V_S = satellite velocity
C = velocity of propagation (161,880 n.mi./sec)
R = Radius of the earth (3440 n.mi.)
h = satellite altitude

For ITOS satellite, h = 1460 km = 790 n.mi. The velocity of that satellite could be calculated from [11]

$$V_S = \sqrt{\frac{\mu}{R+h}}$$

where $\mu = 6.274 \times 10^4$ n.mi.^{3}/sec^2

Substituting for R and h in the above equation results in V_S = 3.84 n.mi./sec

From equation (6) the maximum doppler frequencies are obtained for three typical frequencies in the three bands of interest. The results are shown in the following table.

f_o	$f_{d\,max}$
140 MHz	± 2.7 KHz
400 MHz	± 7.74 KHz
1600 MHz	± 30.96 KHz

Maximum Rate of Change of Doppler:

From equation (5) it is evident that the maximum rate of change of doppler depends on R_0, the range between the satellite and the RFI source at the closest approach.

For ITOS type satellite R_0 may vary from 790 to 2460 n. mi. depending on the source latitude substituting these limits for R_0 in equation (5), the following values are obtained for maximum rate of change of doppler frequency $(d\,fd/dt)_{max}$.

Frequency	$(d\,fd/dt)_{max}$	
f_0	R_0 = 790 n. mi.	R_0 = 2460 n. mi.
140 MHz	16.2 Hz/sec	5.2 Hz/sec
400 MHz	46.4 Hz/sec	14.8 Hz/sec
1600 MHz	185.6 Hz/sec	59.2 Hz/sec

SIGNAL PROCESSING

The expected interference at low orbiting satellite may vary with the geographical location, the interfering signals may have different modulations, signal bandwidth, and polarization. In some regions the carrier frequencies may be very close to each other. In addition, due to the doppler effect, the received frequencies will be constantly changing. For these reasons, if a receiver is designed with a predetermined bandwidth, it is quite likely that there may be several signals within that bandwidth. To properly resolve the different signals and determine their doppler curves, the following signal processing is recommended.

It is assumed, at the outset, no signal processing will be attempted at the satellite, as it complicates the satellite. For RFI experiment, the satellite carries a wideband antenna and a tunable receiver. The required antenna characteristics will be considered in a later section. The design details of the satellite receiver will not be given here, but the following capabilities are assumed. The received signals are first filtered in a preamplifier, and the first frequency conversion bring the signals to the intermediate frequency range, where they are further filtered. A second conversion brings the spectrum to the baseband range (say 1 KHz to 26 KHz for 25 KHz bandwidth or 1 KHz to 201 KHz for 200 KHz bandwidth). These signals are multiplexed and sent to ground station for further processing.

The proposed ground station processing is shown below:

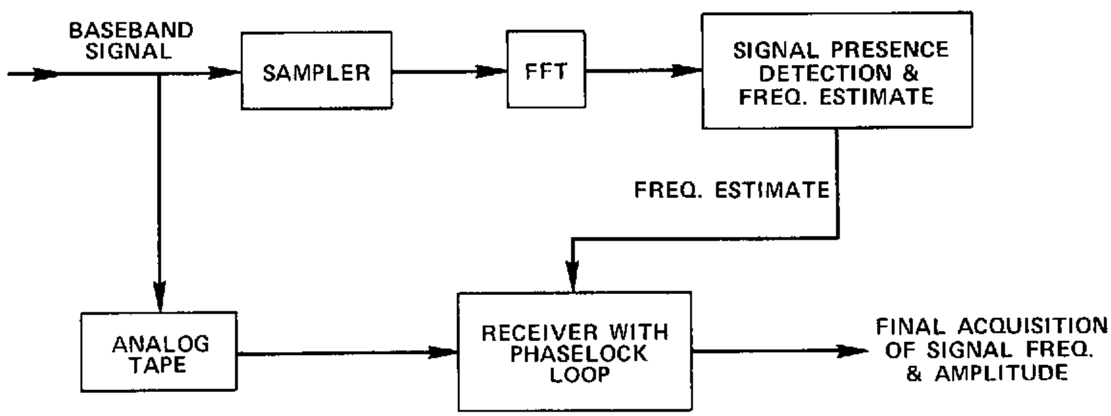

Figure 1. Ground Station Signal Processing

The channel center frequency is translated to zero frequency and the resulting signal is filtered by a low pass filter. The signal is analogue recorded on tape and also sampled for detection of signal presence. The sampler takes complex point samples at a rate of twice the composite signal bandwidth. These samples are processed using a complex fast Fourier transform (FFT) to detect the presence of a signal and roughly estimate its carrier frequency (say within 1 KHz).

If a signal was detected, the estimated frequency is used to control the phase lock loop receiver for final acquisition of signal frequency and amplitude as shown in Fig. 1.

ANTENNA ANALYSIS

In this section a brief discussion is given on the required antenna characteristics for RFI measurement. Since, the frequency range of interest is from 0.1 to

1.7 GHz, broadband antennas are mandatory to minimize the number of antennas required.

An antenna with small beamwidth is desired to find the source location by spacial discrimination. However, the difficulties associated with the use of such antennas preclude this approach as explained below. To obtain small width, physically large antenna would be required. Due to small beamwidth, a low probability of RFI source signal would occur as the spacecraft travels at a high orbital velocity, the spacecraft's stability and pointing accuracy would be critical, and it takes long time to complete earth coverage. Since only a narrow swath could be covered per orbit. For these reasons it is required to use a simple antenna which has an isotropic pattern from horizon to horizon.

For ITOS type of satellite, the beamwidth required to cover the earth could be shown to be 108.4°.

Another parameter to be considered is the required polarization. Since, a large percentage of earth based signals are linearly polarized and the fact that the Faraday rotation of linearly polarized signals below 1 GHz passing through the ionosphere results in a polarization ambiquity, it is recommended that the circularly polarized antennas be used.

Log conical or cavity backed spirals have the required characteristics of broad-bandwidth, broad-beamwidth and circular polarization.

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