# The Analysis of the Airplane Flutter on Low Band Television Broadcasting Signal

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**Abstract:**

The paper studies effect of quasi-periodic or airplane flutter phenomenon on television broadcasting signal. Airplane flutter is a very important problem. It causes the receiving antenna to receive both direct signal by the Tx (Transmitter antenna) and reflected signal scattered by the airplane with phase delay. The sum of two signals results in fading, sometime collapse and distortion of picture on TV screen. We performed measurement and modeling this phenomenon on TV signal when the airplane flew across and range Tx and Rx (Receiver antenna).

The frequency 60.75MHz (Aural frequency of CH3) is used under tests. A single scatter multipath model is introduced. It is used to duplicate some of the measured data and show the dependence of power variation on the airplane fluttering. The fluctuation of the airplane flutter phenomenon was calculated to be around 2-4dB. The Yaki antenna is used for improving airplane flutter problem because it can make high gain and high directivity.

**Keywords**: Airplane flutter, Quasi-periodic, Interference on TV signal.

## I. INTRODUCTION:

The interference occurred on television broadcasting system when the airplane flies over the path between TV transmitter and TV receiver. This is called "airplane flutter" problem.

This phenomenon is caused by multipath of signal, when both direct and reflected signals arrive at the Rx antenna at different time. It's difference from multipath caused by reflected signal from the buidings. The airplane movement causes scattering angle change at all time. The phase differences between direct and reflected signals make great fluctuations in receiving signal power. The phenomenon occurs in both VHF and UHF frequency [1] [2] as we can observed in the place near the airport.

The measurement and simulation of airplane flutter in Thailand when the airplane flies across Tx and Rx was reported [2][3]. Stacker antennas were used to solve this problem near an airport in Japan [7] [8][9] because it receives less vertical signal than other antennas since reflected signal by airplane is usually received in upper direction. There are reports of the propagation of UHF and L-band from balloon to mobile van moving along the ground [4]. The simulation of multipath fading for analog and digital television transmission in broadcasting channel was reported [5]. This result shows changes in phase delay, adding a variable Doppler shift to the multipath signal. This can particularly damage digital systems, when delay spread cause blocks of data to overlap, and result in inter-symbol-interference. In analog systems, periodic signal cancellation, notches in amplitude across the signal spectrum will occur where a change in delay results in destructive phase addition.

This paper shows the measurements and simulation of signal strength fluctuation caused by airplane when it flies across and range of Tx and Rx antennas, at altitude of airplane about 3000m above ground.

## II. EXPERIMENT:

**Measurement Setup:** The measurement parameters are on Table 1. We performed measurement at Nakornnayok province and KMITL. The CH3 has 60kW output power with 230m of antenna height. At the receiving point we used ANRITSU WI-208 field strength meter with standard dipole 4m above ground.

Table 1. Measurement parameters

| | |
|---|---|
| CH3 Transmitting antenna height | 230m |
| Output power | 60kW |
| Receiving antenna height (Standard dipole) | 4m |
| CH3 Frequency (Aural freq.) | 60.75MHz |
| Distance from Tx to Rx (KMITL)<br>Distance from Tx to Rx (Nakornayok province) | 45km<br>120km |
| Airplane | Boeing747 |
| Airplane's altitude<br>Airplane's speed | 3000m<br>360km/h |
| Field strength meter | Anritsu(WI-208) |

The field strength of CH3 was recorded when the airplane flew over the observation point. The distance from CH3 Nongkam, Bangkok to KMITL is about 45km. The Boeing747's airplane usually flies across Tx and Rx antennas at altitude about 3000m with speed about 360km/h. At Nakornnayok province the airplane flew in range Tx and Rx antennas with same altitude and speed. The Figure 1 shows airplane routes for Nakornnayok and KMITL.

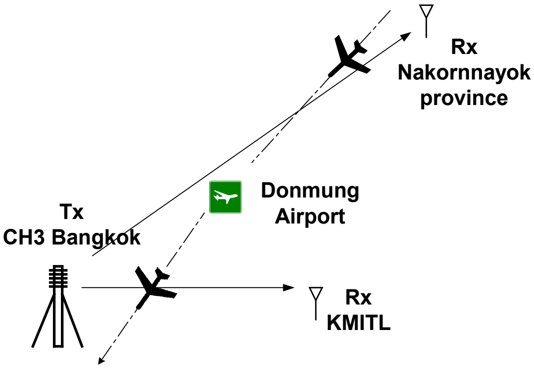

Figure 1. The airplane flew range at Nakornnayok measure point and flew across at KMITL measure point.

**Measurement Results:**

At Nakornayok measure point, as the airplane was preparing to landing at Donmung airport, it moved past Rx antenna in the range of Tx and Rx antennas. The signals from Tx antenna arrive at the Rx antenna in two paths. First, direct signals that can receive about 20dBuV/m and second, reflected signal scattered by the airplane when it flew past the Rx antenna. The maximum of signal strength was around 2dB with about 30 seconds duration time.

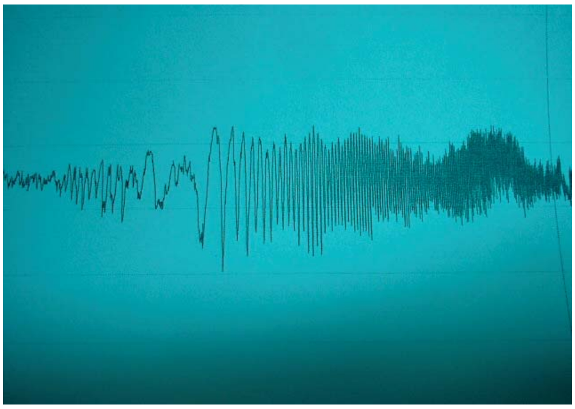

Figure 2. Signal strength and fluctuation at Nakornnayok province. The maximum signal fluctuation was 2dB and duration time was about 30sec.

At KMITL measure point, the airplane took off from Donmung airport and flew across the Tx and Rx with speed of 360km/h and altitude about 3000m. The direct signal can receive about 40dBuV/m. The reflected signal scattered by airplane when the airplane moving pass it can make signal strength fluctuate maximum around 4dB and the duration time 20sec. The duration time is shorter than at Nakornayok province. Fig.3 shows the airplane flutter pattern at KMITL. The airplane was at altitude 3000m and speed 360km/h.

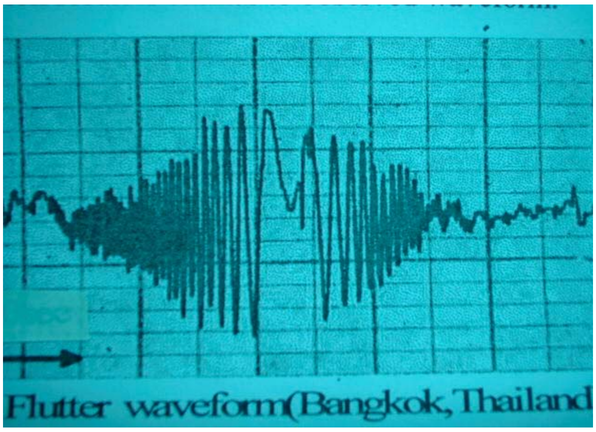

Figure 3. The airplane flutter pattern was received at KMITL. The maximum signal fluctuation was 4dB.

**Bistatic Radar Equation:**

Bistatic radar Equation is used for bistatic target RCS, denote by $\sigma_{B}$. It is used for accurate prediction scatter of signal strengths. The radar cross section (RCS) of a scattering object is defined as the ratio of the power density of the signal scatted in the direction of the receiver to the power density of the radio wave incident upon the scattering object. We assume that the bodies of aircraft equal ellipsoid for easier calculation and one widely accepted approximation for the ellipsoid back scattered RCS is given in Equation (1) by [6].

$$\sigma = \frac{\pi b^4 c^2}{(a^2 (\sin\alpha)^2 + c^2 (\cos\alpha)^2)^2} \qquad (1)$$

$\sigma$ = Radar cross section scattering ($m^2$)
a and b = ellipsoid width (m)
c = ellipsoid length (m)
$\alpha$ = The scattering angle (m)

**Range, Cross range and Doppler shift of the airplane:**

Airplane moving into the direction between Tx and Rx antenna as at the Nakornnayok province is called *"range pattern"* shown in Fig. 4.

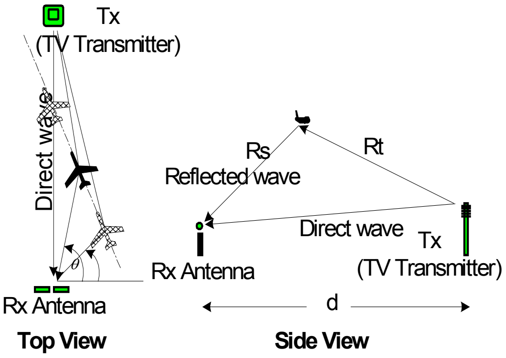

Figure 4. The airplane moved into the direction of Rx and Tx antennas at Nakornayok measure point, it is called "range pattern".

Consider an airplane moving at a constant velocity $V_{air}$, along a path segment having length d between point Tx and Rx, it reflected signals from Tx as illustrated in Fig. 4. The airplane has very slant angle; the θ angle can vary from 0-180° when it moved past Rx antenna and toward the Tx antenna. The phase change in the received signal due differences in path length and apparent change in frequency or *"Doppler shift"*, is given by $f_d$ [6], as in Equation (2).

$$f_d = \frac{V_{air}}{\lambda} \bullet (\pm)\cos\theta \qquad (2)$$

where

$\theta$ = Angle between airplane and arrival of the wave to Rx antenna (degree)

$V_{air}$ = velocity of airplane (m/h)

$\lambda$ = Wave length (m)

Equation (2) relates the Doppler shift to the airplane velocity and the spatial angle between the direction of airplane and the direction of the arrival of the wave to Rx antenna. As can be seen from equation (2) that if the airplane moves toward the direction of the arrival of wave to Rx antenna. The Doppler shift will be positive, the (+) plus sign (i.e., the apparent received frequency increased when θ = 0 to 90 degrees) and if the airplane moves away from the direction of arrival of the wave to Rx antenna. The Doppler shift will be negative, (-) the minus sign (i.e., the apparent received frequency is decreased when θ = 90 to 180 degrees).

The case of at KMITL is the "*cross range pattern*" is occurred when the airplane moved across between Tx and Rx antenna in Fig.5. In this case, the airplane moved in the direction perpendicular to the direction of arrival of the transmitted signals. The θ can vary from 0-180 degrees. The Doppler shifts also occurred in this case.

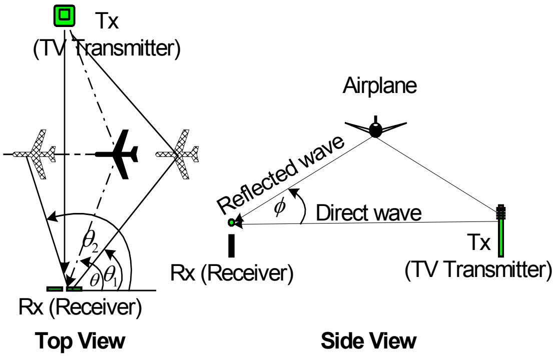

Figure 5.The airplane moved across Tx and Rx antennas at KMITL measure point. The θ can vary from 0 to 180 degrees and assume ϕ is nearly constant.

In this case θ vary from 0-180 degrees. The $\theta_1$ vary from 0 to 90 degrees the frequency decreased when the airplane moved toward the line-of-sight between Tx and Rx antennas, the (+) plus sign in Eq. (2). The $\theta_2$ vary from 90 to 180 degrees the frequency increased when the airplane moved far away from the line-of-sight, (-) minus sign in Eq. (2).

Figure 6 shows Doppler shift frequency versus θ angle from 0 to 180 degrees respect the direction of the arrival of the wave to the Rx antenna. When the airplane make 0 and 180 degrees of θ angle. The Doppler shift frequency ($f_d$) is maximum at around 20Hz; the Doppler shift is 0Hz when the airplane makes θ angle at 90 degree.

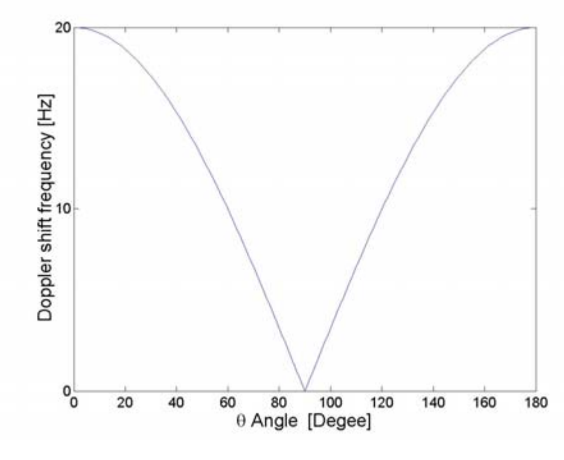

Figure 6. Doppler shift frequency vs θ angle of airplane respect the direction of the arrival of the wave to the Rx antenna from 0 to 180 degrees.

## III. SIMULATION:

Airplane flutter behavior can be described by a simple multipath scattering. The model has been formulated with the objective of increasing the understanding of some of the measured signal behavior and also for predicting effects for which no experiments have yet been carried out.

The Rx antenna can receive both direct and reflected wave scattered by airplane. That is the vector sum of two waves constituting the received signal. Fig. 7 is for simplicity of the numerical evaluation of the model modify from [4], the assumptions are that 1) there is only 1 scatter, 2) RCS of the airplane is bases on ellipsoid, and 3) the receiving antenna is standard dipole.

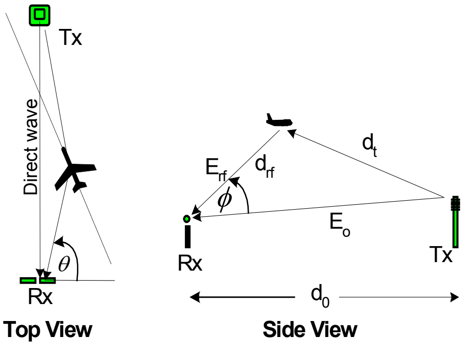

Figure 7. The geometry used for the derivation of a simple single scatter model of the airplane flutter.

It is then easy to derive the formula for the received electric field strength $E_r$ as Equation (3).

$$E_r = E_0 + \frac{1}{D_r} \cdot \sigma \cdot e^{(j\varpi_0 t - \beta)} \cdot e^{[j\frac{V_a}{\lambda} \cdot (\cos\phi + \theta)]} \qquad (3)$$

Where

$E_0$ = line of sight field strength

$$= \frac{\sqrt{30\ P_o D_t}}{d_o}$$

$P_o$ = the power radiate by the transmitting antenna

$D_t$ = directivity gain of transmitting antenna

$D_r$ = directivity gain of receiving antenna (dipole)

$$= \frac{\cos\left(\frac{\pi}{2}\cos\phi\right)}{\sin\phi}$$

$\omega_0$ = 2 π f

β = phase shift

$$= \frac{2\pi}{\lambda}$$

σ = bistatic radar cross section ($m^2$)

λ = wave length (m)

$V_a$ = velocity of airplane (m/sec)

$d_0$ = path length between Tx and Rx antennas (m)

The results from both actual measurement and the model are similar, data measured on Fig.2 at Nakornnayok and Fig.3 at KMITL compared to the simulation results Fig. 8 and 9 respectively.

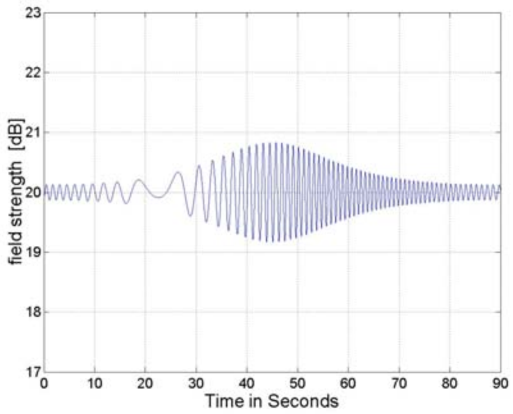

Figure 8. Simulation of airplane flutter at Nakornnayok province. Airplane moving range from Tx to Rx antennas.

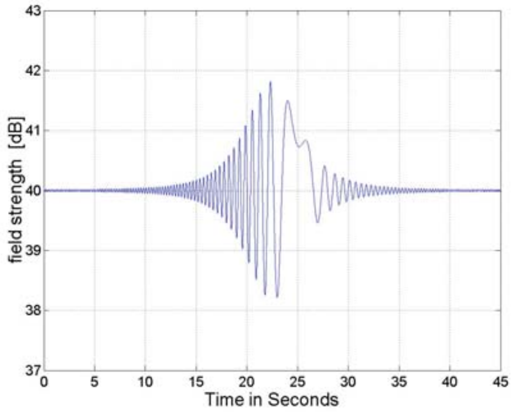

Figure 9. Simulation of airplane flutter at KMITL. The airplane moved cross between Tx and Rx antennas.

At Nakornnayok, The model predicted high frequency fluctuation before the airplane past Rx and low frequency fluctuation after that. The maximum fluctuation was 2dB and duration time was 30sec. At KMITL measure point, the model shows double Doppler shift when the airplane moved forward and far away from the line of sight as it make a $\theta_1$ and $\theta_2$ reference to the line of sight, the maximum fluctuation was 4dB and duration time was 20sec.

## IV. DISCUSSION:

The fluctuation of signal strength is due to phase differences between direct and reflected waves. There are sum and subtract of signal vectors due to the airplane movement. It also changes reflected angle. Thus the signal level is changed at all time. The speed of the airplane, reflected angle and Doppler shift on reflected wave are results in change of frequency modulation. Doppler shift will be positive or negative depends on whether the airplane moved toward or away from the Rx station. The strength of fluctuation depends on the altitude of the airplane, the distance between Tx to Rx antennas, the angle and distance between Rx to airplane. The duration time depends on the direction of the airplane. The long duration time will occur when the airplane moves in range of Tx and Rx.

**Problem Improvement:**

The gain and directivity offered by an array of elements represent a worthwhile improvement both in transmitting and receiving. For the receiving antenna, the directivity reduces the strength of signals coming from the directions not favored, and so helps discriminate against a good dual of interference.

The Yaki antenna is used for improving the airplane flutter problem because it high directivity and high gain. Several independent investigations of the properties of multi-element Yaki antennas have shown that the gain of the antenna expressed as a power ratio is proportional to the length of the array, provided the number, lengths and spacing of the elements are chosen properly.

The directivity D of antenna is given by the ratio of the maximum power density to its average value over a sphere. By Karus [11] to allow an approximate calculation of gain in Eq(4):

$$D = \frac{41{,}000}{\theta^{\circ}_{HP} * \phi^{\circ}_{HP}} \qquad (4)$$

$D$ = approximate directivity (dimensionless)

$\theta^{\circ}_{HP}$ = half power beam width in one principal plane, deg

$\phi^{\circ}_{HP}$ = half power beam width in other principle plane, deg

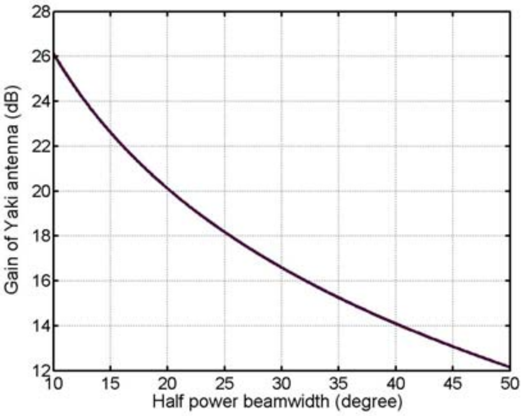

Figure 10. Gain in decibels over isotropic as a function of the half power beam width in the Yagi antenna.

The results of calculation are shown in terms of the half power beam-width (HPBW), Figs 10. In this case the antenna consists of a driven element, one reflector and series of directors properly spaced and tuned. Thus, If the antenna is to have a gain of 18dB Fig 10 shows that the 25 degree of half power beam-width

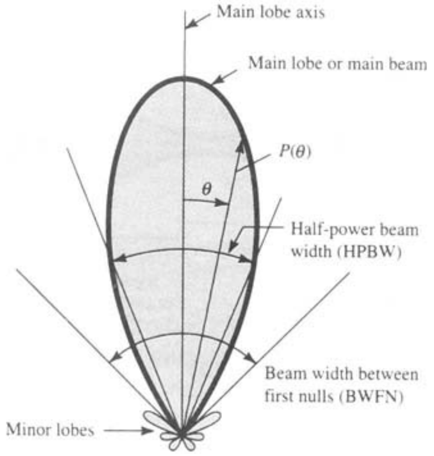

Figure 11. The half power beam width of Yaki antenna

The field pattern can present in polar coordinates, and, to show the minor lobes in more detail. If the pattern is symmetrical, the three-dimensional pattern is a figure of revolution of Fig.11 around the main-lobe axis similar to the pattern in Fig. 12.

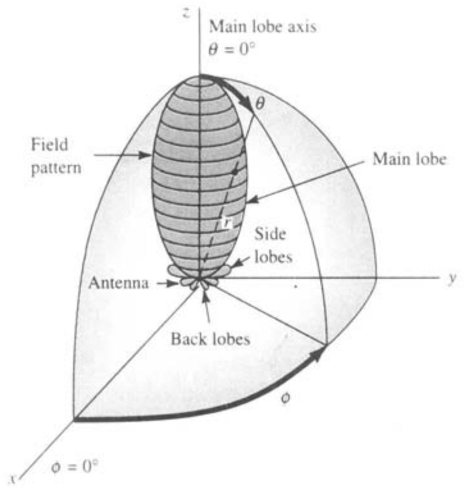

Figure 12. The antenna field pattern width coordinate system.

## V. CONCLUSIONS:

This paper studies the signal fluctuation by airplane scattering signals to Rx antenna. The paper discussed one way of measuring and simulation of some patterns of airplane flutter. The different locations and directions of Boeing747 airplane are under tests. At Nakornnayok measure point the maximum signal fluctuation is around 2dB and duration time of 30 seconds. It has lower fluctuation but longer duration time than at KMITL due to distance between Tx antenna and the airplane, and its movement in range of Tx and Rx. The model is based on multipath scattering. It has been formulated to duplicate some measured data.

From the experiment results, the interference at KMITL was higher then at Nakornayok but with shorter duration time. The difference of the effect between the places is due to flying pattern of the airplane. This problem can be improved by using the high gain or high directivity antenna because it can reduce the interference signal scattered by the airplane.

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