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600 MHz ROUND TRIP PHASE CORRECTION AND EFFECT OF WAVEGUIDE RIPPLE AND NON-RECIPROCITY OF PATH ON IF PHASE

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1.0 INTRODUCTION

Due to waveguide length changes phase of the reference 600 MHz delivered at an antenna varies. Also, the phase of an IF signal will change depending on the variation in the waveguide length and frequency of the IF. Variation in the waveguide path length is estimated using measured 600 MHz round trip phase. First in this report we work out the amount of correction to be applied to each IF at baseband due to 600 MHz round trip phase variations. In working out this correction it is assumed that the waveguide path changes are the same in both forward and return directions and also that the length changes are the same at all frequencies of interest. In the latter part of this report we attempt to work out the effect of waveguide pass band ripple and non-reciprocity of the path on the IF phase.

2.0 600 MHz ROUND TRIP PHASE CORRECTION

A simplified block diagram illustrating the effect of the waveguide path length change by $(\Delta T/2\pi)$ μ-seconds for channels A and C IF signals is shown in Figure 1. Here we first consider observing at C-Band. As shown in Figure 1, let:

f_o = Observing Frequency (in MHz)
f_{L6A} = 2-4 GHz Synthesizer Frequency, Channel A (in MHz)
f_{L6C} = 2-4 GHz Synthesizer Frequency, Channel C (in MHz)

From Figure 1 it can be seen that for the path change by $(\Delta T/2\pi)$ the phase of IF signal for channel A changes by $(-f_o+2f_{L6A}+2400)\ \Delta T$ and that for C channel IF changes by $(-f_o+2f_{L6C}+3600)\ \Delta T$. Also, the measured 600 MHz round trip phase changes $\phi_{600RT} = 1200\ \Delta T$. Therefore, in terms of ϕ_{600RT}, a measured quantity, the phase correction for channel A IF is $(-f_o+2f_{L6A}+2400)\ \frac{\phi_{600RT}}{1200}$ and that for channel C is $\frac{(-f_o+2f_{L6C}+3600)}{1200}\ \phi_{600RT}$.

Phase correction for other IF channels and different bands of observing are found in a similar way. The calculated values of the phase corrections are given in Table 1.

Table 1 - Phase correction for all IF channels and observing at different bands. f_2 = frequency of upconverter pump in MHz = 3200, f_3 = frequency of 17-20 GHz L.O. in MHz. f_o = observing frequency in MHz, f_{L6A} = 2-4 GHz synthesizer frequency in MHz for channel A and f_{L6C} = 2-4 GHz synthesizer frequency in MHz for channel C.

	Channel A, B	Channel C, D
L-Band	$\frac{\phi_{600RT}}{1200}\ (-f_o-2f_2+2f_{L6A}+2400)$	$\frac{\phi_{600RT}}{1200}\ (-f_o-2f_2+2f_{L6C}+3600)$
C-Band	$\frac{\phi_{600RT}}{1200}\ (-f_o+2f_{L6A}+2400)$	$\frac{\phi_{600RT}}{1200}\ (-f_o+2f_{L6C}+3600)$
Ku-Band	$\frac{\phi_{600RT}}{1200}\ \left[f_o-2(f_3-f_{L6A})+2400\right]$	$\frac{\phi_{600RT}}{1200}\ \left[f_o-2(f_3-f_{L6C})+3600\right]$
K-Band	$\frac{\phi_{600RT}}{1200}\ \left[-f_o+2(f_3+f_{L6A})+2400\right]$	$\frac{\phi_{600RT}}{1200}\ \left[-f_o+2(f_3+f_{L6C})+3600\right]$

3.0 EFFECT OF WAVEGUIDE RIPPLE AND NON-RECIPROCITY OF PATH ON IF PHASE

Effect of pass band ripple and non-reciprocity of the waveguide communication channel can be considred by assuming path lengths to be different at each frequency and also to be different in forward and returned directions. Block diagram in Figure 2 shows this situation for observing at C-Band and using channel A IF. As shown in the figure, let the path delay

from CR to VR at 1200 MHz = $T_{1F}/2\pi$
from CR to VR at 1800 MHz = $T_{2F}/2\pi$
from VR to CR at 1200 MHz = $T_{1R}/2\pi$
from VR to CR at 1800 MHz = $T_{2R}/2\pi$
from VR to CR at channel A IF = $T_A/2\pi$

Further, for simplication of expressions, let

$$T_{2F} - T_{1F} = \Delta T_F$$
$$T_{2R} - T_{1R} = \Delta T_R$$

and

$$T_A = T_{1R} + \Delta_A.$$

Referring to Figure 2 phase of channel A IF when translated to baseband for C-Band observing can be written as:

$$\Phi_A^C = f_{L6A}(T_{1F}+3\Delta T_F) - (f_o-f_{L6A})T_A + 1200(T_{1F}+T_{1R}+3\Delta T_F)$$

Where f_o = observing frequency
f_{L6A} = frequency of 2-4 GHz synthesizer-channel A

$$\Phi_A^C = -(f_o-f_{L6A})\Delta_A - (f_o-f_{L6A})T_{1R} + f_{L6A}(T_{1F}+3\Delta T_F) + 1200(T_{1F}+T_{1R}+3\Delta T_F)$$

$$= -(f_o-f_{L6A})\Delta A + f_o\frac{(T_{1F}-T_{1R})}{2} - \frac{T_{1F}+T_{1R}}{2}(f_o-2f_{L6A}-2400) - 3\Delta T_F(f_{L6A}-1200) \qquad \text{-----(1)}$$

Again, referring to Figure 2 we can write the 600 MHz round trip phase, (ϕ_{600RT}), a quantity measured at CR, in terms of quantities on previous page:

$$\phi_{600RT} = -600(T_{1F}+T_{1R}) - 1800(\Delta T_F+\Delta T_R)$$

or

$$(T_{1F}+T_{1R}) = -\frac{\phi_{600RT}}{600} - 3(\Delta T_F+\Delta T_R). \qquad \text{-----(2)}$$

Substituting from (2) in (1) we get:

$$\phi_A^C = -(f_o-f_{L6A})\Delta_A+f_o\left(\frac{T_{1F}-T_{1R}}{2}\right)-\left(\frac{f_o}{2}-f_{L6A}-1200\right)-\left(\frac{\phi_{600RT}}{600} - 3\Delta T_F-3\Delta T_R\right) +$$

$$3f_{L6A}\cdot\Delta T_F+3600\Delta T_F$$

The phase correction to channel A IF phase due to 600 MHz round trip phase changes from Table 1 is:

$$\frac{\phi_{600RT}}{600}(-f_o+2f_{L6A}+2400) \qquad \text{-----(3)}$$

When this correction is applied, the phase-error of channel A IF at base band for C-Band observing is given by:

$$\Delta\phi_A^C = -(f_o-f_{L6A})\Delta_A+f_o\left(\frac{T_{1F}-T_{1R}}{2}\right)+\left(\frac{f_o}{2}-f_{L6A}-1200\right)(3\Delta T_F+3\Delta T_R)+$$
$$3f_{L6A}\Delta T_F+3600\Delta T_F$$

$$= -(f_o-f_{L6A})\Delta_A+f_o\left(\frac{T_{1F}}{2}-\frac{T_{1R}}{2}+\frac{T_{2F}}{2}-\frac{T_{1F}}{2}\right)+f_o\Delta T_F+(1.5f_o-3f_{L6A}-3600)\Delta T_R$$

$$= -(f_o-f_{L6A})\Delta_A+f_o\left(\frac{T_{2F}-T_{2R}}{2}\right)+f_o\Delta T_f+(2f_o-3f_{L6A}-3600)\Delta T_R$$

-----(4)

Values of the phase-errors for other IF channels and other observing bands are found in a similar manner. The results for C-Band and L-Band and for IF channels A and C are given on the next page.

Observing Band	IF Channel	Phase Error
C	A	$\Delta\Phi_A^C = -(f_o - f_{L6A})\Delta_A + f_o\left(\frac{T_{2F}-T_{2R}}{2}\right) + f_o\Delta T_f +$ $(2f_o - 3f_{L6A} - 3600)\Delta T_R$
C	C	$\Delta\Phi_C^C = -(f_o - f_{L6C})\Delta_C + f_o\left(\frac{T_{2F}-T_{2R}}{2}\right) + f_o\Delta T_F +$ $(f_o - 2f_{L6C} - 3600)\Delta T_R$
L	A	$\Delta\Phi_A^L = -(f_o + f_2 - f_{L6A})\Delta_A + f_o\left(\frac{T_{2F}-T_{2R}}{2}\right) + f_o\Delta T_F +$ $(2f_o + 3f_2 - 3f_{L6A} - 3600)\Delta T_R$
L	C	$\Delta\Phi_C^L = -(f_o + f_2 - f_{L6A})\Delta_C + f_o\left(\frac{T_{2F}-T_{2R}}{2}\right) +$ $(f_o + 3f_2 - 3f_{L6C})\Delta T_F + (f_o + 2f_2 - 2f_{L6C} - 3600)\Delta T_R$

Where f_{L6C} = frequency of 2-4 GHz synthesizer - channel C

$\Delta_C = T_C - T_{2R}$

and T_C = Path delay from VR to CR at channel C IF.

Depending upon the ripple structure each term in the above expressions could be a few tenths of a degree to almost 1^o per 0.1 dB peak ripple. If reciprocity of the waveguide communication channel is not perfect the error terms in an expression may easily add to give a total of more than 1^o/0.1 dB of ripple in the waveguide transmission. Thus, in the observed fringe visibility a peak to peak error of 4^o or even more may be present just due to 0.2 dB peak to peak ripple in waveguide transmission to each antenna. At C-Band this may barely be tolerable but at L-Band it is already far exceeding the system phase stability specification of 1^o/GHz of observing frequency.

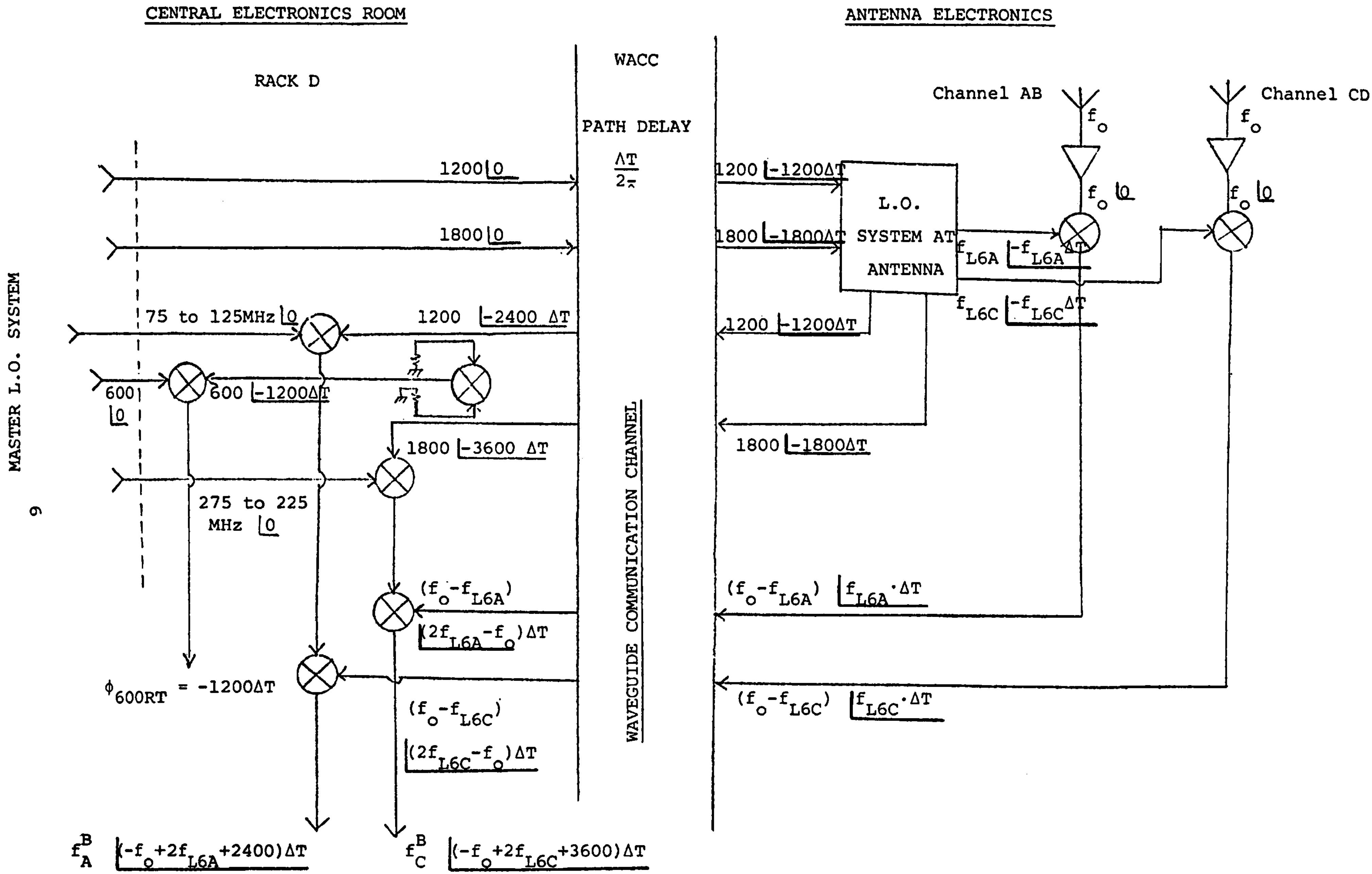
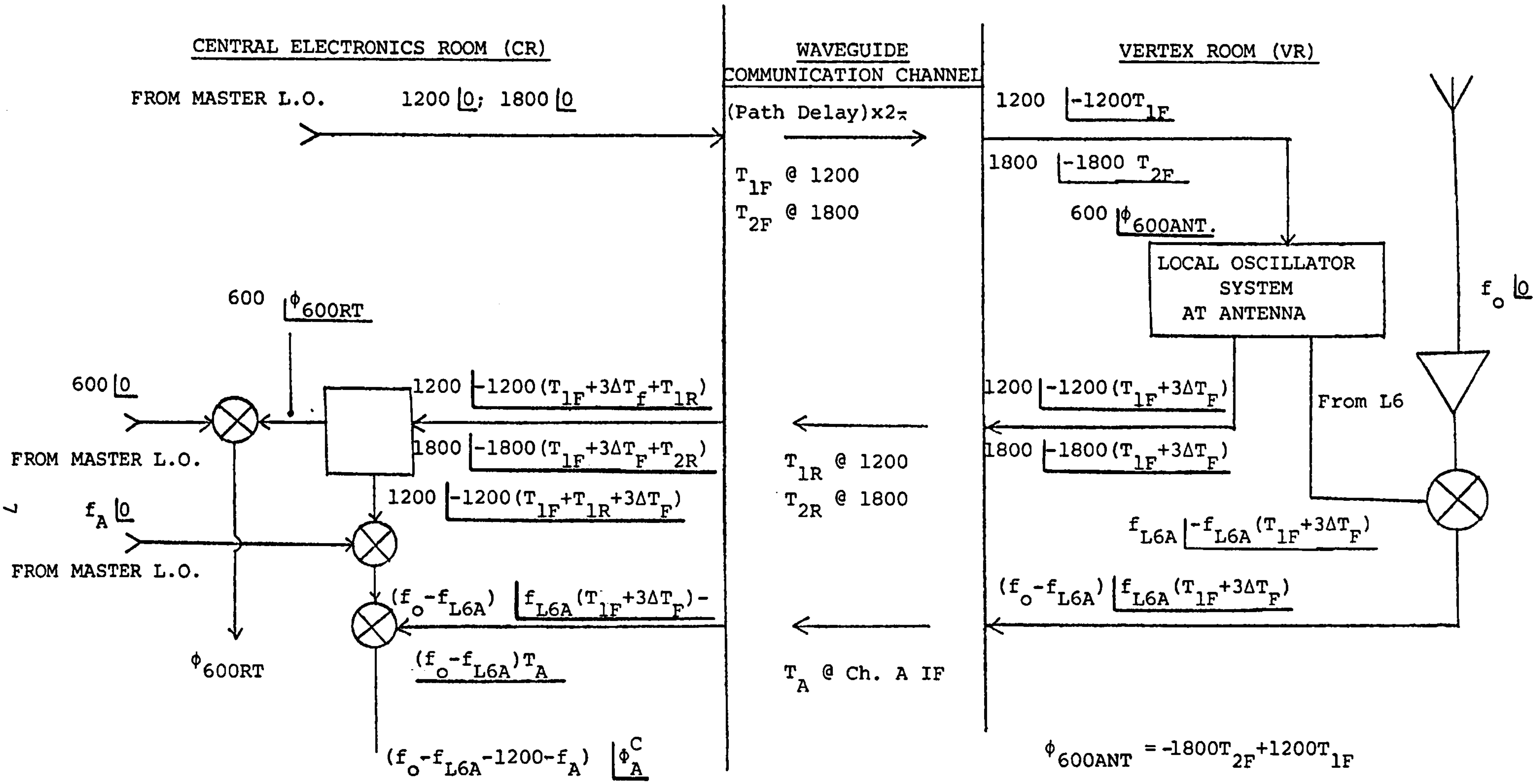


FIGURE 1 – BLOCK DIAGRAM SHOWING 600 MHz ROUND TRIP PHASE CORRECTION FOR OBSERVING AT C-BAND FOR IF SIGNAL CHANNELS A AND C



$$\phi_A^C = f_{L6A}(T_{1F}+3\Delta T_F)-(f_o-f_{L6A})T_A+1200(T_{1F}+T_{1R}+3\Delta T_F)$$

$$\begin{aligned}\phi_{600ANT} &= -1800T_{2F}+1200T_{1F}\\ &= -1800T_{2F}+1800T_{1F}-600T_{1F}\\ &= -600T_{1F}-1800(T_{2F}-T_{1F})\\ &= -600(T_{1F}+3\Delta T_F)\end{aligned}$$

$$\begin{aligned}\phi_{600RT} &= -1800(T_{1F}+3\Delta T_F+T_{2R})+1200(T_{1F}+3\Delta T_F+T_{1R})\\ &= -600(T_{1F}+3\Delta T_F)-1800(T_{2R}-T_{1R})-600T_{1R}\\ &= -600(T_{1F}+T_{1R})-1800(\Delta T_F+\Delta T_R)\end{aligned}$$

FIGURE 2 - BLOCK DIAGRAM SHOWING EFFECT OF WAVEGUIDE RIPPLE AND NON-RECIPROCITY OF PATH ON IF PHASE FOR C-BAND OBSERVATIONS AND IF CHANNEL A