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Determination of MkIII Videoconverter Sky Frequency

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I. Introduction.

When conducting observations with the MkIII filter bank, an observer must understand the operation of the MkIII videoconverters to properly determine observed sky frequencies. This memorandum derives a simple formula for calculating the sky frequency corresponding to a particular videoconverter local oscillator setting. The videoconverter sky frequency is dependent upon the VLA observing band because the VLA baseband is configured differently for different observing bands. The theory of operation of the image rejection mixers in the videoconverters is also briefly discussed.

II. Videoconverter Response to a Single Frequency Component.

The VLA baseband is upconverted to video frequency with the MkIII local oscillator, $\nu_{LO} = 150$MHz. We shall temporarily assume that the VLA baseband is composed of a single frequency component, ω, to simplify our discussion. The video signal is split between all videoconverters, and is represented mathematically by

$$\cos(\omega t)\cos(\omega_{LO}t) = \frac{1}{2}[\cos(\omega_{LO} - \omega)t + \cos(\omega_{LO} + \omega)t] \tag{1}$$

The frequency component $\omega_U = \omega_{LO} + \omega$ is the upper sideband frequency component and $\omega_L = \omega_{LO} - \omega$ is the lower sideband component. One may also think of the mixing process as a convolution between two sets of delta functions (Figure 1). From Case A in the Appendix, the upper and lower sideband outputs of a single videoconverter are proportional to

$$\text{USB} = \cos(\omega_{LO} + \omega - \omega_{VC})t \tag{2}$$

$$\text{LSB} = \cos(\omega_{VC} - \omega_{LO} + \omega)t \tag{3}$$

where $\nu_{VC} = \omega_{VC}/2\pi$ is the local oscillator setting of the videoconverter. Therefore, if one injected an 8MHz monochromatic signal into the MkIII prior to LO mixing and configured a videoconverter for a local oscillator setting of 157MHz and a bandwidth of 4MHz, the USB output would contain a 1MHz signal and the LSB output would contain nothing because the LSB signal lies outside the videoconverter band. Similarly for Case B in the Appendix when the injected signal is 4MHz into the 157MHz LO videoconverter, the LSB output would contain a 3MHz signal and the USB output would contain nothing. Note that $\nu = \omega/2\pi$ must lie within the VLA baseband bandwidth ($0 < \nu < \Delta\nu_{VLA}$) to be detected by a videoconverter.

III. Videoconverter Sky Frequency.

If we consider multiple frequency components in the VLA baseband, the upper and lower sidebands at the MkIII appear as in Figure 2 for P, L, C, and K observing bands. The upper scale in the figure shows the locations of the VLA sky frequencies. ν_C is the center frequency of the band, and $\Delta\nu_{VLA}$ is the VLA baseband bandwidth. The lower scale in Figure 2 shows the locations of the corresponding MkIII video frequencies. To determine the sky frequency specified by a videoconverter local oscillator, ν_{VC}, one must compare the two scales. When $\nu_{VC} > \nu_{LO}$ sky frequency increases with increasing videoconverter local oscillator frequency. For the specific case shown in the figure, $\nu_{VC} > \nu_{LO}$, the videoconverter local oscillator frequency corresponds to a sky frequency of

$$\nu_{CVC} = \nu_C - [(\nu_{LO} + \Delta\nu_{VLA}/2) - \nu_{VC}] \tag{4}$$

If the sky frequency of the upper sideband is specified as the center of the videoconverter upper sideband then,

$$\nu_{CUSB} = \nu_C + (\nu_{VC} - \nu_{LO}) - \frac{1}{2}(\Delta\nu_{VLA} - \Delta\nu_{VC}) \tag{5}$$

where $\Delta\nu_{VC}$ is the videoconverter bandwidth. Similarly the sky frequency of the videoconverter lower sideband is

$$\nu_{CLSB} = \nu_C + (\nu_{VC} - \nu_{LO}) - \frac{1}{2}(\Delta\nu_{VLA} + \Delta\nu_{VC}) \tag{6}$$

For the case $\nu_{VC} < \nu_{LO}$, sky frequency increases with decreasing videoconverter local oscillator frequency, and

$$\nu_{CUSB} = \nu_C + (\nu_{LO} - \nu_{VC}) - \frac{1}{2}(\Delta\nu_{VLA} + \Delta\nu_{VC}) \tag{7}$$

$$\nu_{CLSB} = \nu_C + (\nu_{LO} - \nu_{VC}) - \frac{1}{2}(\Delta\nu_{VLA} - \Delta\nu_{VC}) \tag{8}$$

For X and U observing bands, the upper scale in Figure 2 should be modified such that $\nu_C + \Delta\nu_{VLA}/2$ corresponds with ν_{LO} of the lower scale and $\nu_C - \Delta\nu_{VLA}/2$ corresponds with $\nu_{LO} \pm \Delta\nu_{VLA}$. In the case $\nu_{VC} > \nu_{LO}$, sky frequency decreases with increasing videoconverter local oscillator frequency, and

$$\nu_{CUSB} = \nu_C - (\nu_{VC} - \nu_{LO}) + \frac{1}{2}(\Delta\nu_{VLA} - \Delta\nu_{VC}) \tag{9}$$

$$\nu_{CLSB} = \nu_C - (\nu_{VC} - \nu_{LO}) + \frac{1}{2}(\Delta\nu_{VLA} + \Delta\nu_{VC}) \tag{10}$$

In the case $\nu_{VC} < \nu_{LO}$, sky frequency decreases with decreasing videoconverter local oscillator frequency, and

$$\nu_{CUSB} = \nu_C - (\nu_{LO} - \nu_{VC}) + \frac{1}{2}(\Delta\nu_{VLA} + \Delta\nu_{VC}) \tag{11}$$

$$\nu_{CLSB} = \nu_C - (\nu_{LO} - \nu_{VC}) + \frac{1}{2}(\Delta\nu_{VLA} - \Delta\nu_{VC}) \tag{12}$$

IV. Videoconverter Operational Considerations.

Mixing at the videoconverter produces a signal at a frequency determined by the difference between ν_{LO} and ν_{VC}. To avoid detection of this signal, the videoconverter local oscillator should be set such that $|\nu_{LO} - \nu_{VC}| > \Delta\nu_{VC}$. Although the maximum videoconverter bandwidth is $\Delta\nu_{VC} \leq 4$MHz, experimental data show that a videoconverter local oscillator setting as high as 156MHz produces a signal level at 6MHz comparable with the noise level in the videoconverter band. Therefore, videoconverter local oscillator settings should be limited by $\nu_{VC} < 144$MHz for $\nu_{VC} < \nu_{LO}$ and $\nu_{VC} > 156$MHz for $\nu_{VC} > \nu_{LO}$.

The videoconverter local oscillator settings are further restricted by the VLA baseband bandwidth. The videoconverter sidebands should not lie outside the VLA baseband. For example, the upper sideband of a videoconverter configured for a local oscillator frequency of 200MHz will lie outside a VLA bandwidth of 50MHz. For $\nu_{VC} > \nu_{LO}$, the restriction on ν_{VC} imposed by $\Delta\nu_{VLA}$ is

$$\nu_{VC} < \nu_{LO} + \Delta\nu_{VLA} - \Delta\nu_{VC} \tag{13}$$

For $\nu_{VC} < \nu_{LO}$, the restriction is

$$\nu_{VC} > \nu_{LO} - \Delta\nu_{VLA} + \Delta\nu_{VC} \tag{14}$$

The restrictions imposed on ν_{VC} by $\Delta\nu_{VLA}$ are independent of VLA observing band.

V. References.

Thompson, A. R., Moran, J. M., and Swenson, G. W., 1986, Interferometry and Synthesis in Radio Astronomy, John Wiley and Sons, New York.

Appendix: The Image Rejection Mixer.

The image rejection mixer, shown in Figure 3, consists of a set of mixers which produces the separate upper and lower sideband signals. The input signal consisting of upper, ω_U, and lower, ω_L, sideband frequency components is mixed with quadrature local oscillators. Both mixer outputs are filtered of high frequency components. A 90 degree phase lag is introduced into output B before the outputs are added or subtracted to produce the "pure" upper or lower sideband signals, respectively. The content of the USB and LSB signals depends upon the magnitude of the local oscillator frequency.

Case A: $\omega_L < \omega_{VC} < \omega_U$

$$\mathrm{A} = \frac{1}{2}[\cos(\omega_U - \omega_{VC})t + \cos(\omega_{VC} - \omega_L)t] \tag{A1}$$

$$\mathrm{B}(-\pi/2) = \frac{1}{2}[\cos(\omega_U - \omega_{VC})t - \cos(\omega_{VC} - \omega_L)t] \tag{A2}$$

$$\mathrm{USB} = \mathrm{A} + \mathrm{B}(-\pi/2) = \cos(\omega_U - \omega_{VC})t \tag{A3}$$

$$\mathrm{LSB} = \mathrm{A} - \mathrm{B}(-\pi/2) = \cos(\omega_{VC} - \omega_L)t \tag{A4}$$

Case B: $\omega_L < \omega_{VC}, \omega_U < \omega_{VC}$

$$\mathrm{A} = \frac{1}{2}[\cos(\omega_{VC} - \omega_U)t + \cos(\omega_{VC} - \omega_L)t] \tag{A5}$$

$$\mathrm{B}(-\pi/2) = -\frac{1}{2}[\cos(\omega_{VC} - \omega_U)t + \cos(\omega_{VC} - \omega_L)t] \tag{A6}$$

$$\mathrm{USB} = 0 \tag{A7}$$

$$\mathrm{LSB} = \cos(\omega_{VC} - \omega_U)t + \cos(\omega_{VC} - \omega_L)t \tag{A8}$$

Case C: $\omega_L > \omega_{VC}, \omega_U > \omega_{VC}$

$$\mathrm{A} = \frac{1}{2}[\cos(\omega_U - \omega_{VC})t + \cos(\omega_L - \omega_{VC})t \tag{A9}$$

$$\mathrm{B}(-\pi/2) = \frac{1}{2}[\cos(\omega_U - \omega_{VC})t + \cos(\omega_L - \omega_{VC})t \tag{A10}$$

$$\mathrm{USB} = \cos(\omega_U - \omega_{VC})t + \cos(\omega_L - \omega_{VC})t \tag{A11}$$

$$\mathrm{LSB} = 0 \tag{A12}$$

Figure 1: Mixing as a Convolution of Two Sets of Delta Functions

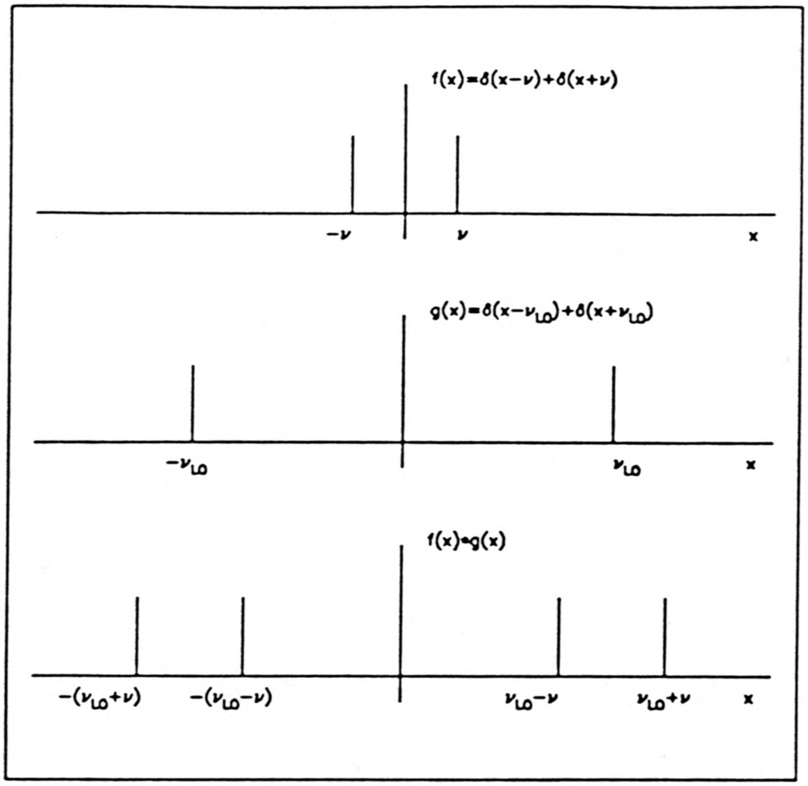

Figure 2: Comparison of VLA Baseband to MkII Videoconverter Frequencies

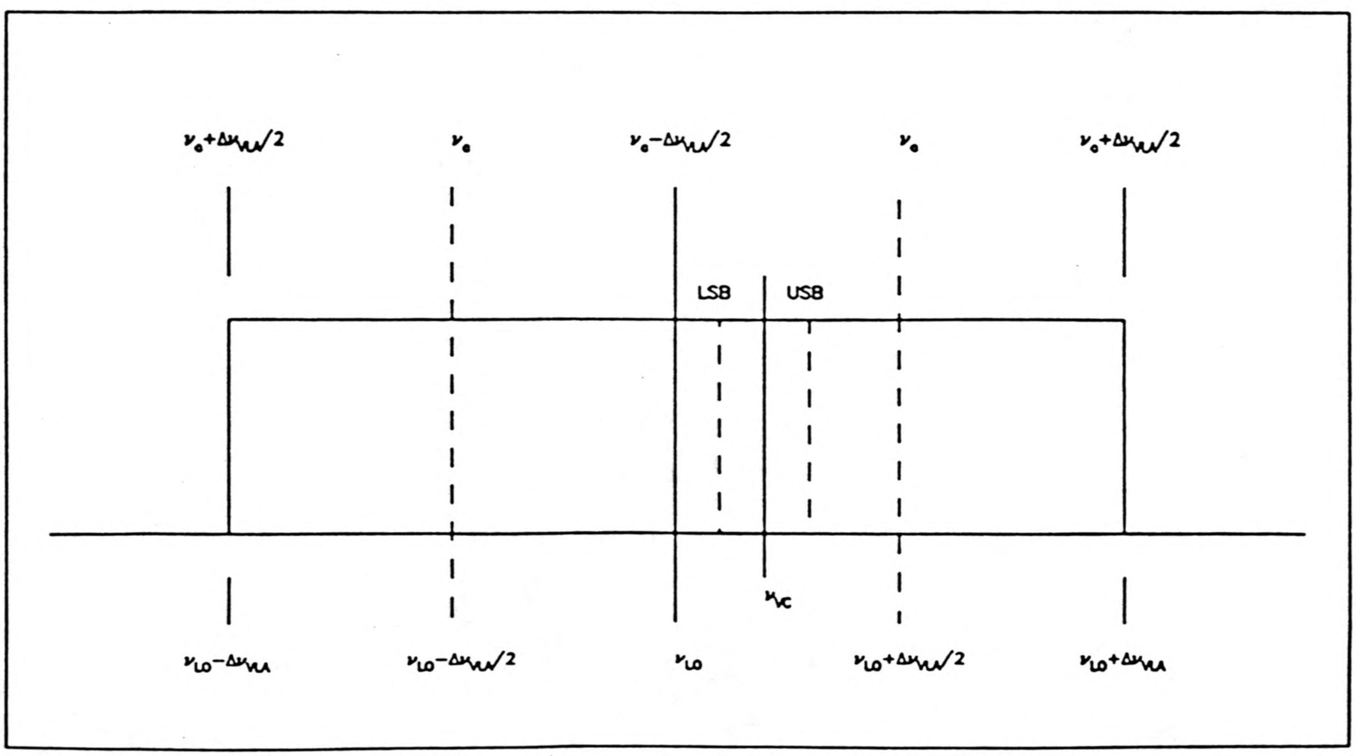

Figure 3: Image Rejection Mixer