Interoffice

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VLA ELECTRONICS MEMORANDUM NO. 148

To: VLA Steering Committee, A. Shalloway, R. Escoffier, A. R. Thompson, S. Weinreb — December 1, 1975

From: B. Clark

Subject: WHAT TO DO WITH ALL THOSE MULTIPLIERS.

As you know, the current design for the line system calls for twice as many multipliers as had been designed into the continuum system. There is naturally some discussion of what we could use these for during continuum observations instead of letting them sit idle. I have looked into three possible uses (which, because they involve quite different sampler configurations, are mutually exclusive). These are: 1) Saving money by eliminating the need for a quadrature channel; 2) Expanding the field of view by making two 25 MHz channels; and 3) Increasing the bandwidth. None of these three are very satisfactory. Forced to make a choice, I would pick number 3, and not implement the required changes to the waveguide system at present.

The considerations I am discussing here do not particularly apply to the use of the system in a psuedo-line mode, as discussed by Fraser Owen in VLA Scientific Memo #121, which, incidentally, is in error by a factor of two in the number of channels and channel bandwidths in its table 1.

I. Eliminating the quadrature channel.

It is well known that the imaginary part of the cross-correlation function can be calculated knowing only the real part. The difficulty lies in estimating it from only a small number of samples of the real part of the cross-correlation function. With four multipliers, we may calculate it for the phase tracking center, plus and minus one bit, and either plus or minus two bits. A pure imaginary correlation has nulls at alternate bits (assuming a square band pass) so the two bit lag is not useful. The least square estimator of $\mathrm{Im}(C_0)$ is

$$\frac{\pi}{4}(C_+ - C_-).$$

This has the unfortunate property of having a different signal-to-noise-ratio (SNR) from the real part. It is worse by the factor $\frac{2\sqrt{2}}{\pi} = .90$. While not cripling, having different signal-to-noise-ratios in real and imaginary parts is certainly intutively distressing.

If we set the fourth channel to say, plus three bits, the estimator is

$$\frac{\pi}{4}\left(C_{+}-C_{-}+\frac{1}{3}C_{+++}\right)\frac{18}{19}$$

and the SNR is $\frac{2\sqrt{2}}{\pi}\;\frac{\sqrt{19}}{18} = 0.925$

II. Making two 25 MHz channels.

The assymetry in SNR between real and imaginary parts may be eliminated by disposing the four lag channels symmetrically about the phase tracking center. This could be done by running the samplers at twice the rate (200 MHz) and feeding alternate bits into the present quadrature delay lines. Then the four multipliers may be used to calculate the correlation function at lags of $\pm\frac{1}{2}$ bit (ie ± 5 ns; C_{+} and C_{-}) and $\pm 1\frac{1}{2}$ bit (15 ns; C_{++} and C_{--}). One may then generate two more or less independent frequency channels by Fourier transforming. One has a certain liberty in choosing the weights and channel centers. One may choose to satisfy the following conditions: 1) The two frequency channels are mirror images in the 25 MHz center frequency; 2) The noise on the two channels is uncorrelated; and 3) The sum of the two channels gives the least square estimate of the 50 MHz correlation function at the phase tracking center. Then, the two frequency channel correlation coefficients are

$$C_1 = W_2C_{--}e^{-3i\phi}+W_1C_{-}e^{-i\phi}+W_1C_{+}e^{i\phi}+W_2C_{++}e^{3i\phi}$$

$$C_2 = W_2C_{--}e^{-3i(\phi-\frac{\pi}{2})}+W_1C_{-}e^{-i(\phi-\frac{\pi}{2})}+W_1C_{+}e^{i(\phi-\frac{\pi}{2})}+W_2C_{++}e^{3i(\phi-\frac{\pi}{2})}$$

where

$W_1 = 1.060$

$W_2 = 0.638$

$\phi = 25.^{\circ}5.$

These correlation coefficients do not individually have equal SNR in real and imaginary parts, though their sum does. Because of this, and because their band passes differ fairly drastically for the real and imaginary parts, using these 25 MHz channels to correct for delay-beam effects is not so straightforward as one might like.

One could, of course, make two independent 25 MHz channels, with analog filters, which is quite attractive, but does require yet another set of quadrature samplers.

III. Doubling the bandwidth.

Obviously, with twice as many multipliers as we need for 50 MHz, we could provide another set of samplers and delay lines and process another pair of 50 MHz bands. There is, however, an easier, more elegant way of doing it.

As presently origanized in the continuum system, we calculate the following products of sine and cosine components:

$$C_1 * C_2 \quad \text{or} \quad S_1 * S_2$$

$$C_1 * S_2 \quad \text{or} \quad S_1 * C_2$$

Clearly, if we calculate all four products, instead of just two, we can post hoc calculate

$$C_1 * C_2 + S_1 * S_2 + i(C_1 * S_2 - S_1 * C_2)$$

which is a full complex correlator. The reason it is nice to have a complex correlator is that the sampling theorem for complex signals states that they must be sampled only at the bandwidth, not at twice the bandwidth. We could therefore feed hundred MHz bandwidth signals into the present samplers (redesigning the quadrature network, of course, so that it would work over this band) and thus double the bandwidth of the delay-multiplier system.

The present waveguide communication system probably cannot be reasonably modified to provide hundred MHz IF's. Also, Sandy has indicated that with the present modem philosophy, this bandwidth cannot be supported at all on the A configuration because of signal-to-noise problems in the millimeter equipment.

BC:jm