

INTERFEROMETER SIGNAL DEMODULATION IMPROVES TRACKING SENSITIVITY

WILLIAM K. COOPER
Physical Science Laboratory
New Mexico State University

Summary. A considerable improvement in signal to noise ratio has been achieved in narrow band interferometer trackers by demodulating the telemetry signal prior to the final stage of i-f amplification. This system has an effective signal bandwidth much greater than the noise bandwidth. Signal to noise improvements of 10 dB are typical.

Introduction. S-band interferometer controlled telemetry tracking systems have been successfully used at White Sands Missile Range since 1969.¹ These systems have been found to be highly reliable and have a large advantage over other tracking systems in that they automatically acquire signals anywhere within $\pm 13^\circ$ of boresight.

These systems employ a 10 ft. dish antenna for the data channel and three 9 in. horn antennas for the tracking channel. The horn antennas feed the interferometer receivers which generate the tracking errors to drive the pedestal. The final i-f amplifier is very narrow banded (8 kHz) and most of the signal power of a typical broad band telemetry signal is thus outside the pass band of this amplifier. The signal demodulation process described in this paper uses a priori information from the data receiver to map the spectrum of the telemetry signal inside the 8 kHz bandwidth of the final i-f amplifier. This mapping process, of course, destroys the telemetry information, but preserves the relative phase of the signals from which the tracking errors are derived.

Tracking System. The simplified functional block diagram for this system is shown in Figure 1.

The interferometer antennas are mounted so that movement of the pedestal in the elevation axis changes the relative range of the elevation (EL) antenna with respect to the center reference (C) antenna, but not the azimuth (AZ) antenna. The converse is true for movement in azimuth. The pulse of the signal in the EL(AZ) antenna with respect to the reference antenna is thus proportional to the pointing error of the antenna system.

¹ "Interferometer - Controlled Telemetry Tracking System," W. K. Cooper National Telemetry Conference 1969 record.

The outputs of each antenna are fed to a limiter and preamplifier. The output of each amplifier is sent to a down converter which heterodynes the 2.2 GHz signals down to 73.6 MHz. These signal pairs are then sent to the interferometer receivers (one for elevation and one for azimuth) where they are heterodyned twice more, resulting in a 465 kHz signal in which both the EL(AZ) and reference signals are combined for amplification in a single i-f strip. When these combined signals are peak detected, the results are 500 Hz signals which carry the required phase information. (See Appendix) These 500 Hz signals are sent to phase detectors where the tracking errors are extracted.

When the system is in the auto track mode, these signals are sent to the servo amplifiers, which closes the tracking loop.

The frequency of the first local oscillator is controlled by an automatic frequency control unit which forces the frequency in the last i-f strip to be held, on the time average, to within twenty cycles to the set frequency (nominal 465 kHz).

The data signal enters the system at the feed of the ten foot dish; this signal is preamplified and sent to the data receiver. The 10 MHz output of the data receiver carries the information describing the instantaneous frequency of the data signal. This information is used to tune the second local oscillator, at modulation rate, in such a way as to keep the interferometer tuned to the instantaneous carrier frequency. Thus, in principle, this maps the entire power spectrum of the telemetry signal into a single spectral line at the center of the 465 kHz i-f strip pass band.

In practice, however, the signal arriving from the data receiver is delayed by time T , about $2 \mu\text{s}$. This delay means that the instantaneous local oscillator frequency is not precisely what it should be, (it is what it should have been $2 \mu\text{s}$ earlier) and the demodulated (difference) frequency is thus off by this same amount.

The error in demodulation frequency is $\epsilon = f(t) - f(t-T)$. From the definition of the derivative,

$$\epsilon \approx \frac{df(t)}{dt} T.$$

It is thus seen that the demodulation is not complete unless the system is compensated by adding a delay to the tracking channel signal.

Tests. A series of tests were run to determine the extent to which the system could be compensated by placing a delay line (composed of RG-8 cable) in series with the 73.6 MHz signal. The delay was adjusted until the narrowest spectrum was observed at the output of the demodulator (2nd mixer). For the purpose of making this adjustment, the

transmitter was modulated with a 100 kHz triangular wave form at a 225 kHz deviation. This deviation was chosen because the carrier term (J_0) disappears. Figure 2 is a photograph of the spectrum at the second mixer output when the demodulator is turned off. This figure shows the missing J_0 term at the center. The large spectral line at the far right is feed-through from the third local oscillator. Figure 3 is the spectrum at the same place when the demodulator is turned on. One observes that most of the power has now been mapped into the carrier (J_0) line and that this line is 10 dB higher than the largest line available prior to demodulation. Since only one such line can be passed by the final i-f amplifier this represents a 10 dB increase in the signal to noise ratio in the tracking channel.

When the same test is run without the delay, the results are as shown in Figures 4 and 5 respectfully. Even in this case the demodulation results in a large J_0 line where none existed before, but the increase in signal to noise ratio is negligible. Figure 6 is the spectrum when the demodulator is turned off and the transmit signal is a typical fm-fm telemetry signal with a deviation of ± 90 kHz. When the demodulator is activated with the correct delay, the spectrum becomes as shown in Figure 7 for a net improvement of 12 dB in signal to noise ratio.

Conclusion. Interferometer signal demodulation has proved to be a useful technique in improving the signal to noise ratio in the tracking channel of an interferometer controlled telemetry tracker. The important limitations on this technique are set by the quality of the signal in the data channel. Group delay, dispersion and noise in the data channel each contribute to degradation in tracker performance. Tests have shown that the effect of group delay can be countered effectively by adding an equal amount of delay to the tracking channel.

Further work needs to be done on methods of obtaining the required delay and on interferometer i-f amplifier design to match the data channel dispersion and roll off characteristics.

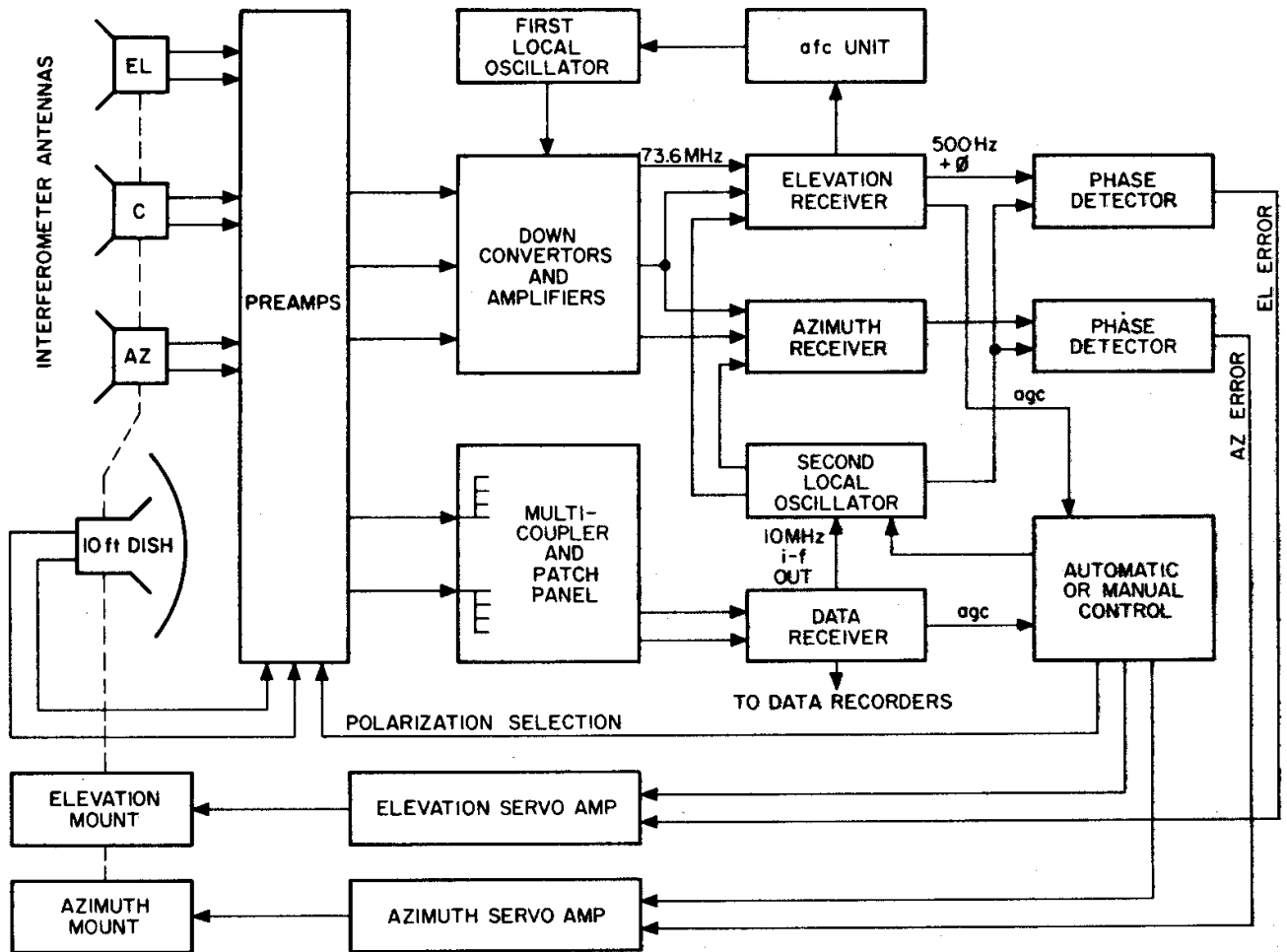


Fig. 1. - Simplified Block Diagram of Interferometer Tracking System.

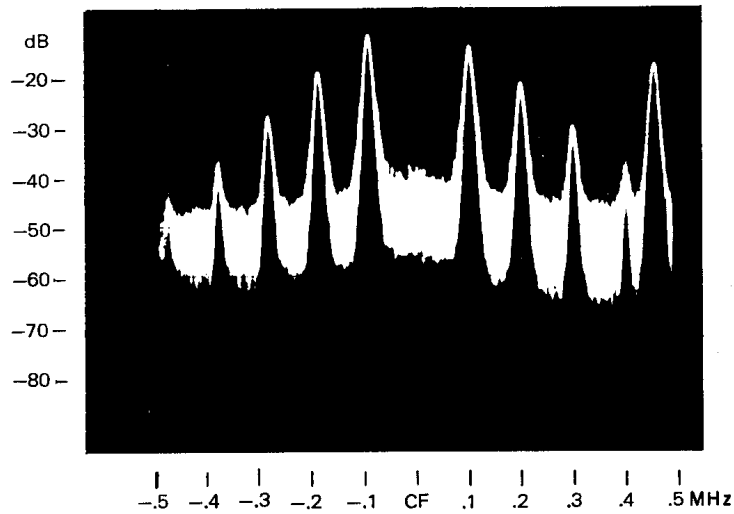


Fig. 2 - Spectrum at output of second i-f without demodulation. Modulation is 100 KHz triangle with ± 225 KHz deviation. Delay cable is in.

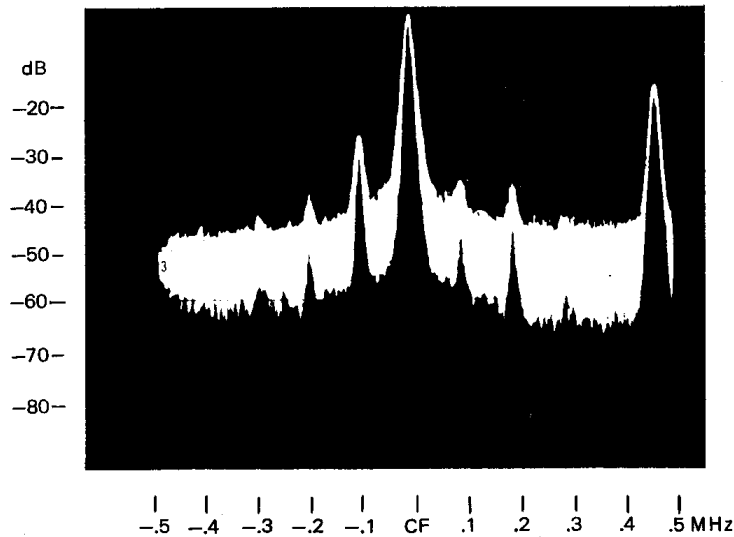


Fig. 3 - Output of second i-f with demodulation. All other conditions same as Fig. 2.

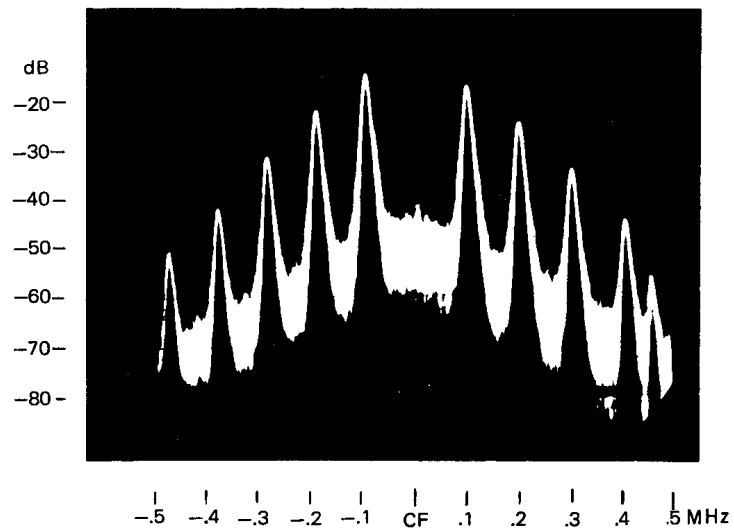


Fig. 4 - Spectrum Output at second i-f with delay cable removed other conditions same as Fig. 2.

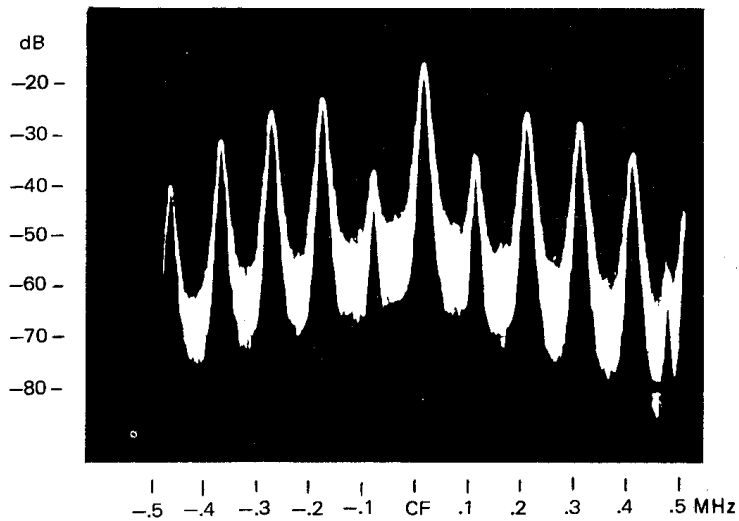


Fig. 5 - Spectrum at Output of second i-f without delay cable and with demodulation a comparison of this figure with Figure 3 shows the degradation in the demodulation process when the group delay is not compensated.

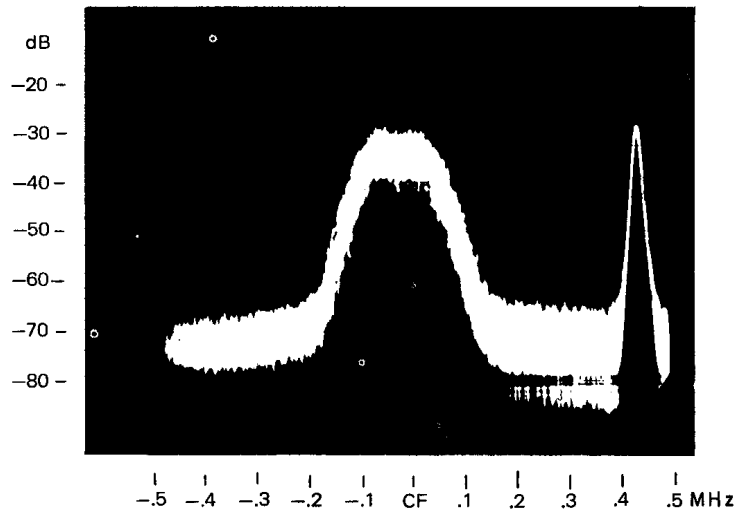


Fig. 6 - Spectrum of output of second i-f without demodulation. The modulation is fm-fm with ± 90 KHz deviation. Delay cable is in.

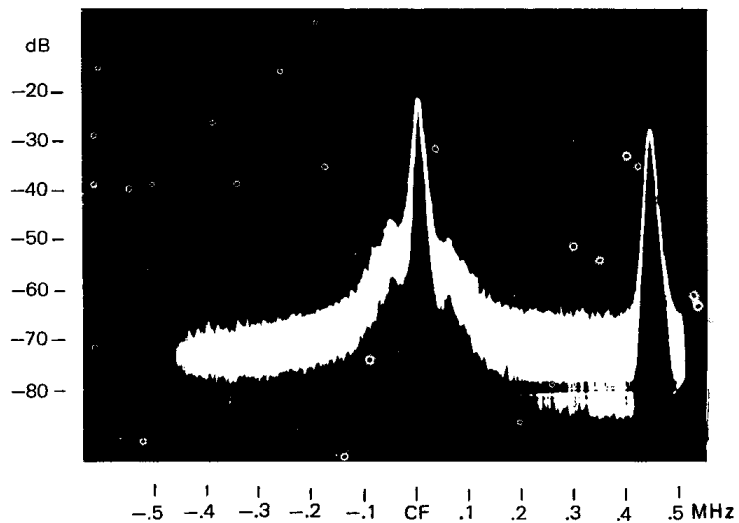


Fig. 7 - Same as 6 with demodulation turned on. This shows a 12dB improvement in signal to noise ratio.

Appendix. Consider an interferometer signal entering the second mixer which has the form of

$$V_1(t) = A \cos (\omega (t) t + \phi), \quad (1)$$

where $\omega_1(t)$ is the frequency modulation of the TM signal, ϕ is the phase containing the tracking error. Consider also a data signal being used as the local oscillator, which has suffered a relative group delay time of T .

$$V_2 = B \cos (\omega_2(t - T)(t - T)), \quad (2)$$

where $\omega_2(t)$ is defined, in terms of the required i-f frequency ω_d , as

$$\omega_1(t) = \omega_1(t) - \omega_d. \quad (3)$$

Therefore, the frequency of the delayed data signal is

$$\omega_2(t - T) = \omega_1(t - T) - \omega_d. \quad (4)$$

The second mixer can be modulated by adding these two signals and peak detecting

$$\text{Sum Sig} = \text{Re} \left(A e^{i\omega_1(t)t} e^{i\phi} + B e^{i\omega_2(t - T)(t - T)} \right). \quad (5)$$

Substituting (4) into (5) yields

$$\text{Sum Sig} = \text{Re} \left(A e^{i\omega_1(t)t} e^{i\phi} + B e^{i(\omega_1(t - T) - \omega_d)(t - T)} \right) \quad (6)$$

$$= \text{Re} \left(A e^{i\omega_1(t)t} e^{i\phi} + B e^{i(\omega_1(t - T)t - \omega_{i-f}t + \phi_2(t))}, \quad (7)$$

where

$$\phi_2(t) = -\omega_1(t - T) T + \omega_d T.$$

Note that by using the first two terms of a Taylor expansion,

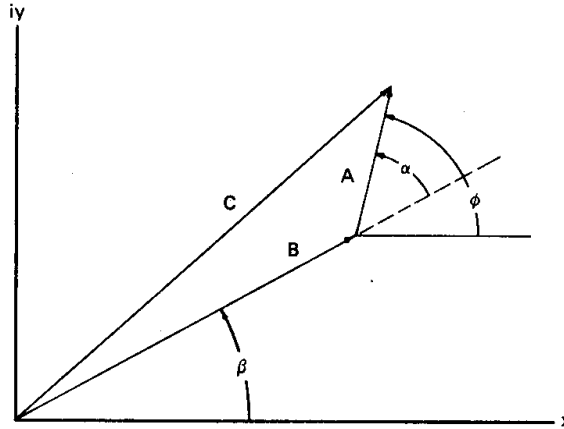
$$\omega_1(t - T) \approx \omega_1(t) - T \frac{d\omega_1(t)}{dt}. \quad (8)$$

Substituting (8) into (7) and factoring yields

$$\text{Sum Sig} = \text{Re} e^{i\omega_1(t)t} \left(A e^{i\phi} + B e^{i\beta} \right) \quad (9)$$

where
$$\beta = -T \frac{d\omega_1(t)}{dt} t - \omega_d t + \phi_2(t)$$

Equation (9) is now in the correct form to draw the phasor diagram for the sum signal. The length of phasor C represents the output voltage of the mixer after peak detecting the sum's signal and low pass filtering.



The angular difference between the two components of the phasor C is

$$\alpha = \phi - \beta \tag{10}$$

$$= (T \frac{d\omega_1(t)}{dt} + \omega_d) t - \phi_2(t) + \phi.$$

Since B is the magnitude of the local oscillator drive and A is the magnitude of the interferometer signal, B is much larger than A.

Therefore,

$$\text{Sum Sig} \approx \text{Re } e^{i\omega_1(t)t} (B + A \cos \alpha) e^{i(\beta + \frac{A}{B} \sin \alpha)} \tag{11}$$

Upon peak detecting, the signal in the i-f strip is

$$\text{i-f Sig} = B + A \cos \alpha$$

$$= B + A \cos \left((T \frac{d\omega_1(t)}{dt} + \omega_d) t - \phi_2(t) + \phi \right). \tag{12}$$

The frequency of this signal is

$$\omega_{i-f} = T \frac{d\omega_1(t)}{dt} + \omega_d \quad (13)$$

The actual frequency of the signal in the i-f strip, ω_{i-f} , is thus seen to be equal to the required i-f frequency, ω_d only if there is no relative group delay, T , or no frequency modulation of the telemetry signal. This points up the necessity of matching the group delay of the interferometer signal, as closely as possible, to that of the data channel.

If the TM signal has an instantaneous frequency of

$$\omega_1(t) = \omega_o + M \text{Cos } \omega_m t \quad (14)$$

Then

$$\begin{aligned} \omega_{i-f} &= \frac{Td(\omega_o + M \cos \omega_m t)}{dt} + \omega_d \\ &= - TM\omega_m \sin \omega_m t + \omega_d \end{aligned} \quad (15)$$

If this signal is to stay within ± 1 KHz of the required i-f frequency, ω_d then

$$TM\omega_m \leq 2\pi \cdot 10^3 \text{ rad/sec} \quad (16)$$

For the case where the deviation of the telemetry signal is $M = \pm 340$ KHz and the modulation frequency is $\omega_m = 400$ KHz, then

$$\begin{aligned} T &\leq \frac{2\pi \times 10^3}{4\pi^2 \times 400 \times 10^3 \times 340 \times 10^3} \\ &\leq 1.17 \times 10^{-9} \text{ sec.} \end{aligned}$$

For this example, which is typical for the worst modulation type in use, the net difference in group delay must be less than 1.17 nanoseconds. The interferometer and data channels can be T - matched by adding extra cable to the transmission lines feeding the interferometer receiver.