the brightest stars of various types, of radio sources of different kinds, and of the lane of dark interstellar matter in Cygnus, the Andromeda galaxy M31, and the Orion nebula were all examined. The maximum possible flux in a 10^{-3}-steradian solid angle in the 300- to 360-μ band is 3×10^{-12} watt/cm^2, corresponding to an average of approximately 2×10^{-23} watt cm^{-2} hz^{-1}. A black-body (optically thick) source 2° or greater in diameter, yielding this flux, woud have a temperature of 10.0°K. For a warmer small or optically thin source providing as much radiation flux in the Rayleigh-Jeans tail of the Planck distribution, the apparent temperature averaged over the 2° width of beam would be 0.6°K.

One should note that the galactic center, Sun, the inner zodiacal light, and most of the planets were not observed during these first flights. However, no observational problems appeared after sunrise, so that all these observations seem possible. Indeed it was encouraging that no effects attributable to variable atmospheric emission were apparent at any time during flight. Further flights will be made at shorter wavelengths and with sensitivity increased by reduction in coverage of the sky.

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10. The radiometer was constructed by one of us (F.J.L.); the other authors constructed the remaining equipment, flew it, and analyzed the data.
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Interferometer Experiment with Independent Local Oscillators

Abstract. *We have operated an interferometer with independent local oscillators and without any communication link of wide bandwidth between the elements of the interferometer. This makes operation possible at very long base lines because, heretofore, construction of the communications link has been the factor limiting the separation of the elements. In our system, coherence at the two elements is maintained through the use of two highly stable, atomic oscillators. The intermediate-frequency output signals are recorded at each element on a high-speed digital tape recorder. Interference fringes are produced later by cross-correlating the two tape records in a digital computer.*

The history of radio interferometry is one of steadily increasing base lines to obtain ever higher angular resolution. The early interferometer experiments maintained coherence by the transmission, through cable, of a local oscillator signal to the two antenna elements from some central location and by the transmission of the two intermediate-frequency signals from the elements back to the central location for correlation (*1*). More recently, there was a need for longer base lines, and the cable system was no longer economical. A microwave transmission link replaced the cables, both for the synchronization of the local oscillators and for the transmission of the intermediate-frequency signals (*2*). Even this system, however, becomes uneconomical for base lines exceeding a few hundred kilometers, because of the line-of-sight requirement on the microwave link.

For very long base lines, the most economical and convenient means of transmitting the broad-band data is apparently through the use of magnetic tape recordings. The radio-frequency signals may be reduced to the frequency range recordable on magnetic tape either by detection (*3*) or by mixing with a local oscillator, which must be coherent between the two elements. The former method has an intrinsically lower signal-to-noise ratio by the factor of the antenna temperature to the system temperature of the radiometer, a very small number for most radio sources.

We have developed and operated an interferometer system which supplies the coherent local oscillator signals at each element by the use of two independent, highly stable atomic oscillators. Figure 1 shows a block diagram of the receiver. The 610-Mhz radio-frequency amplifier comprises two stages, consisting of a parametric amplifier followed by a transistor amplifier. Both signal side bands are heterodyned to the video passband 0 to 250 khz. The 610-Mhz local oscillator signal is provided by an oscillator in phase with the 122nd harmonic of the 5-Mhz stabilized output of the atomic oscillator. These atomic oscillators (*4*) consist of a high-quality crystal oscillator controlled in frequency by a comparison with the microwave line generated by atomic transitions in the rubidium gas.

The video signal is amplified and clipped, so that only the sign of the signal is preserved (*5*). This clipped waveform is sampled at a 720-khz rate, and the resulting bits are recorded on a high-speed digital magnetic tape drive. The sampling is controlled by the atomic frequency standard. The 5-Mhz standard also drives a digital clock, which is set by comparison with the Loran C 100-khz very-low-frequency transmission. The magnetic tape recordings are started by pulses provided every 10 seconds by the digital clock. Further synchronization is provided by writing a gap in the tape records every 0.2 second, so that a character dropped in the process of recording affects only a small part of the whole tape. In making our observations, we record the whole length of a tape on a source. This gives 200 seconds of data, totaling approximately 1.4×10^8 bits of information.

The tapes from the two stations are brought together in a digital computer. One record is delayed (shifted) by an appropriate number of bits, and one-bit multiplication is performed. The resulting product is integrated over an interval of 0.4 msec (288 bits). This compacted product is fitted by a sine wave, at the calculated interferometer fringe frequency, over the successive 0.2-second intervals between gaps in the tape record. The interferometer fringe frequency will not be known exactly, however, because of small frequency errors in the standard oscillators and possibly because of uncertainties in the base-line parameters or the source position. The 0.2-second outputs therefore are Fourier-analyzed over a narrow frequency band rather than simply averaged. Source fringes appear as a peak in this spectrum at the frequency offset. If the atomic standards are carefully adjusted, their offset frequency will probably be less than 0.1 hz at 610 Mhz, and a source position error of 10 seconds of arc will cause an offset frequency of about 0.015 hz on a 1000-km base line, so that a region of the spectrum less than 1 hz wide must be searched.

The digital clocks are set by observing Loran C signals at both stations; hence, their accuracy depends on the propagation times from the nearest Loran station and on the ability to determine the beginning of the Loran pulse in the presence of noise. We estimate the uncertainty in setting the clocks by this method to be about 10 μsec. This uncertainty is several times greater than the reciprocal bandwidth; therefore, a number of delays in the vicinity of the predicted delay are searched for the presence of fringes. The computer time necessary to search a region of 15 delay intervals for an integration time equal to the length of the tape (200 seconds) is about 90 minutes with an IBM 360/50 computer.

Table 1. Interferometer fringe visibility. S_0, 21.5×10^{-26} watt/m^2 per hertz assumed flux for 3C 286 at 610 Mhz; S/S_0, assumed ratio of flux to that of 3C 286; F/F_0, ratio of fringe amplitude to that of 3C 286; γ, fringe visibility.

Source	S/S_0	F/F_0	γ
3C 237	0.51	0.37	0.71
3C 273B	.82	.86	1.02
3C 286	1.00	1.00	0.97
3C 287	0.49	0.54	1.07

The systems were tested by feeding correlated noise at 610 Mhz into the receivers and examining the correlated output. Integration times up to 2½ minutes showed no degradation due to loss of coherence of the local oscillators, as expected from the quoted stabilities of the atomic frequency standards. These tests were run with the correlated noise supplied by a noise tube inserted into the two receivers through directional couplers. We performed a similar experiment in which the correlated noise was the radiation from the radio source Virgo A as received by two adjacent radio telescopes at the National Radio Astronomy Observatory (NRAO), the Howard Tatel 85-foot (24.5 m) antenna, and the 140-foot (42 m) radio telescope. The base-line length of this interferometer was about 1300 wavelengths, so that the fringe rate given by geometrical effects was small compared to the frequency offset of the atomic frequency standards.

A more thorough test of the system was provided by operation as an interferometer between the Howard Tatel telescope at NRAO and the 85-foot telescope at the Maryland Point Observatory of the Naval Research Laboratory. This interferometer has a nearly east-west base line of approximately 461,000 wavelengths at 610 Mhz, giving a fringe rate of approximately 30 hz. Observations of four radio sources known to be of small angular diameter were made on the night of 8 and 9 May 1967. Table 1 gives the observed ratios of fringe strengths, along with the ratios of fluxes and the fringe visibilities, on the assumption that 3C 286 and 3C 287 are unresolved at this frequency and interferometer spacing. These fringe visibilities are consistent with an absolute calibration based on the system noise temperatures and the correlation coefficient observed on Virgo A at the short base line at NRAO. Therefore, we conclude that there are no strong decorrelating effects, equally affecting all sources, that operate over this separation of 220 km and that do not operate over the essentially-zero spacing between the two NRAO telescopes.

The good agreement between fluxes and fringe strengths for 3C 273B, 3C 286, and 3C 287 suggests strongly that all three are unresolved. The corresponding values for fringe visibility (Table 1) are offset from unity inversely as the strength of the sources, under the assumption that the error of measurement is inversely proportional to the strength of the source. The value for 3C 273B was not included in this average because of the uncertainty in the proportion of the total flux contributed by the B component (*6*). The low value of fringe visibility for 3C 237 appears to be significant. All four of these sources show strong interplanetary scintillations at meter wavelengths; hence, they must have strong components less

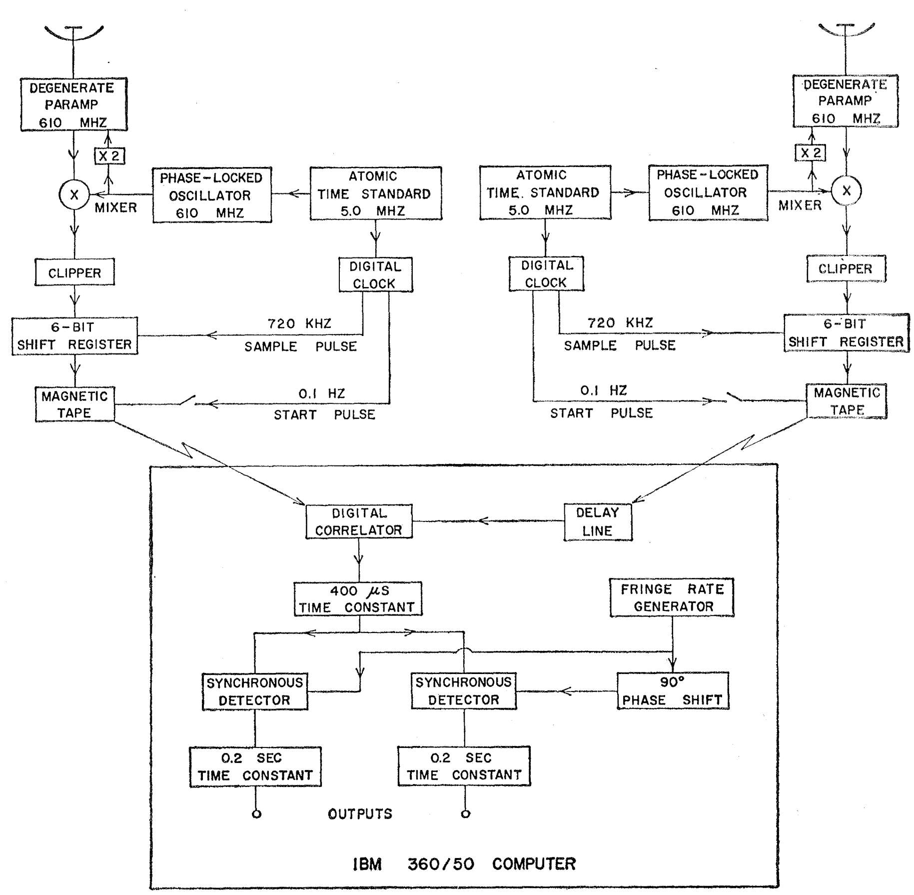

Fig. 1. Diagram of the very long base-line interferometer.

than a few tenths of a second of arc in diameter (7). Radio sources 3C 286 and 3C 287 are unresolved at a wavelength equal to 11 cm with a base line of $1.1 \times 10^6\lambda$; 3C 273B is unresolved at a wavelength equal to 6 cm with a base line of $2.1 \times 10^6\lambda$; and 3C 237 shows fringes characteristic of a double source at a wavelength equal to 21 cm with a base line of $6 \times 10^5\lambda$ (8).

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Oxygen Solubility in Sea Water: Thermodynamic Influence of Sea Salt

Abstract. *Precise measurements of the solubility of oxygen in sea water show that the solubility declines exponentially with increase in salt concentration according to the empirical Setschenow relation. The deviation from linearity is nearly 0.6 percent from the fitted straight-line relations of previous workers. Our experimental data reveal that, in contrast to the effect predicted by the Debye theory, the salting-out decreases with increasing temperature.*

In order to evaluate the influence of sea salt on the solubility of oxygen in water, the ratio of solubility (β) of oxygen in sea water to oxygen in distilled water was determined. As Henry's and Dalton's laws are obeyed at moderate pressures, β is independent of the partial pressure of oxygen with which the solutions are equilibrated. For inert gases in aqueous solutions, β decreases from unity upon the addition of moderate concentrations of electrolytes, this phenomenon being known as salting-out. Previous investigators (*1*) assumed that oxygen solubility depended linearly upon the concentration of sea salt.

The experimental procedure (*2*) entailed the simultaneous saturation of distilled water and sea water with water-saturated air at atmospheric pressure. The solutions were equilibrated concurrently in 12-liter rotating flasks immersed in a large thermostated bath capable of keeping the solutions within 0.01°C of a specific temperature. The air stream was presaturated with water at the temperature of the solutions; the air was blown gently over the top of the water samples in the flasks, whose rotation speed (22 rev/min) was such that no cavitation occurred. This method prevented the formation of bubbles and their attendant supersaturation.

When the solutions were saturated, the concentrations of dissolved oxygen were determined by Carpenter's modification (*3*) of the Winkler titration method. The titration was performed with a dead-stop amperometric end point; the end point was determined with two small platinum indicator electrodes having a potential difference of 182 mv. The ratio of the equivalent volume of titrant, necessary to titrate the oxygen in the sea water, to the corresponding volume for the distilled water gave β directly without one knowing either the partial pressure of oxygen in the air or the exact titrant concentration. In practice, both of these quantities were carefully evaluated so that solubility coefficients could be determined for the individual solutions. It is thought, however, that, whatever small systematic errors there may have been in the determinations of the solubility coefficients, these errors are likely to be canceled out in the measurements of β.

It was necessary to make a small correction in the directly obtained solubility ratios because of the effect of sea salt in lowering vapor pressure. For normal sea water the vapor pressure is about 2 percent lower than that for distilled water (*4*); as the vapor pressure amounts to 0.06 atm at 35°C, the increase in the oxygen partial pressure over sea water may amount to 0.12 percent.

Chlorinity determinations (*5*) were made with a Bradshaw-Schleicher conductivity bridge calibrated against Copenhagen standard water. Paquette (*6*) discussed the probable errors and assumptions inherent in use of this instrument, concluding that the probable error in the range of normal sea water is about 0.002 per mille Cl.

A total of 11 determinations were made, each being replicated from four to six times; they were made at temperatures ranging from 0° to 35°C and at sea-water chlorinities ranging from 6 to 30 per mille.

Determinations were replicated at a carefully controlled temperature of 22.02°C, for sea water of chlorinities near 6, 12, 18, 24, and 30 per mille, to show the salting-out effect unmodified by the pronounced temperature-dependence of the solubility; Fig. 1 shows a distinct regular deviation of β from the linear relation. The semilogarithmic plot shows that the data are well represented by

$$\beta = \exp\left[-k(t)\,\mathrm{Cl}\right] \qquad (1)$$

which is the empirical Setschenow (*7*) relation; it has been shown to be widely useful in representing salting-out data. Between 0 and 20 per mille Cl, the two curves of Fig. 1 never deviate from one another by more than 0.6 percent, so that it is not surprising that the nonlinearity escaped the previous workers, their determined solubility surfaces having a root-mean-square (standard) deviation of more than 0.6 percent.

Carpenter (see *8*) has recently confirmed the nonlinear dependence of solubility although he used a smoothing function that was quadratic in the chlorinity. Our data are well represented by the one-parameter exponential relation which has, in addition to simplicity, a thermodynamic basis. The differ-