The Tape Recorder Interferometer and Small Diameter Radio Sources

Lecture Notes, 1972

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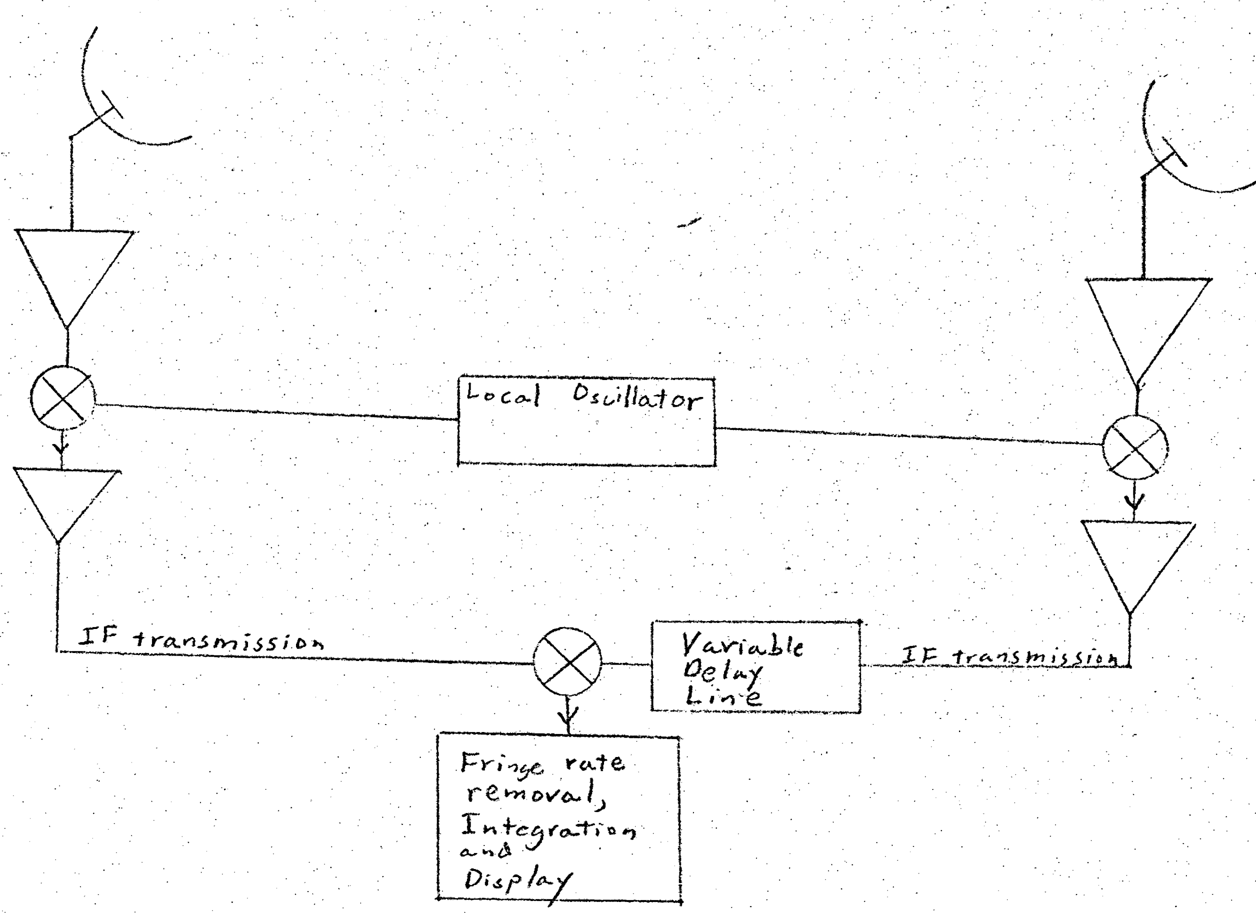
I. The Tape Recorder Interferometer Technique

The tape recorder interferometer is in essence no different from more conventional ones. The over-all block diagram of almost any radio astronomy interferometer is given below.



In this diagram the X'ed circles represent mixers or multipliers -- basically the same process, as both involve multiplying the two inputs and rejecting the high frequency components of the output -- and the triangles denote amplifiers.

The same diagram can be used to discuss tape recorder interferometers with very little modification. The first modification is in the area of the local oscillator, which translates the radio frequency radiation from the radio source down to a more convenient frequency range. As drawn above, the same sinusoidal voltage from a common oscillator is used at the two ends of the baseline. In the tape recorder interferometer, sinusoidal voltages are generated at each end of the interferometer by separate oscillators governed by very good frequency standards. These frequency standards are sufficiently good that for the duration of the observation, essentially identical voltages are being generated at each end of the baseline.

The IF transmission lines in the drawing above are replaced by tape recorder systems. The IF signal is recorded at each end of the baseline, and the tapes are transported to some common location. The two signals are then reproduced in synchronism and are then processed by the remaining parts of the system.

II. Applications of the Technique

A. Orders of Magnitude of Relevant Quantities

Maximum Baseline = $2\, r_{\oplus}$ = 12756 Km

Maximum Geometric Delay = $r_{\oplus}/c$ = 21.3 ms

For operation with a baseline of $r_{\oplus}$ and at frequency F (in GHz)

Baseline in wavelengths = $21.3 \times F \times 10^6$

Fringe Spacing (seconds of arc) = .0097/F

Maximum Fringe rate (Hz) = 1840 x F.

Tape recorder interferometers have been used at frequencies between 24 MHz and 23 GHz.

B. Jupiter Bursts

The high intensity rapid bursts emitted by the planet Jupiter at frequencies between 5 and 30 MHz have been measured to arise in regions less than 1" in size; that is, less than 4000 Km. The radiation is interpreted as arising from cyclotron or stimulated cyclotron emission from electrons energized by local "dumping" of the Jupiter van Allen belts. (See Dulk, 1970, Ap. J. **159**, 671).

C. Interstellar Masers

For a coherent radio source, such as the line emission masers due to inverted state populations in interstellar OH and H_2O clouds, the interferometer measures an intermediate value between the size of the region and the size over which spacial coherence is maintained. The OH maser emission sources have apparent angular sizes of 0.05 to 0.005 seconds of arc, corresponding to a few astronomical units at the source. However, it is suggested that these sources may actually be much smaller regions, whose radiation is spread by small angle scattering from interstellar electron inhomogeneities. The H_2O masers, at a much higher frequency, and hence much less affected by interstellar scattering, have limits on apparent physical sizes as small as 0.1 A.U., smaller than many types of stars.

D. The Synchrotron Sources

Synchrotron radiation is, in the rest frame of the electron, simply cyclotron radiation, or magnetic bremstrahlung, caused by the acceleration of the electron by the magnetic field. The Lorentz transformation causes this radiation to be emitted in a cone of opening angle $\sim \frac{1}{\gamma} = \sqrt{1-\beta^2}$. An electron is accelerated through this angle in a time $\frac{2\pi m_e}{eB} \gamma^2$ so that no radiation of a single synchrotron electron consists of pulses of this duration. These pulses have spectral components up to a critical frequency

$$f_c = \frac{3}{2} \frac{eB}{2\pi m_e} \gamma^2. \quad (1)$$

Because there are many more low energy electrons than high energy ones, selecting the observing frequency effectively selects the energy of the electrons being observed.

The total power emitted by one electron may also be calculated as the blue shifted cyclotron radiation

$$P = \frac{\mu_o e^2 c}{6\pi} \frac{e^2 B^2}{m_e} \gamma^2 \quad (2)$$

Observing at frequencies where the emitted power is a maximum, we may insert the observed power emission in equation 2 to derive a relation between the total number of electrons, the field B, and the energy γ.

By thermodynamic arguments, the emitted brightness temperature cannot exceed the equivalent electron kinetic temperature, i.e. at frequencies where the source is optically thick

$$T_b \sim k\gamma m_e c^2 \tag{3}$$

If one measures the brightness temperature of the sources, then these three relations allow one to solve for the three quantities -- the total number of electrons, the magnetic field, and the energy of the electrons emitting at a specific frequency.

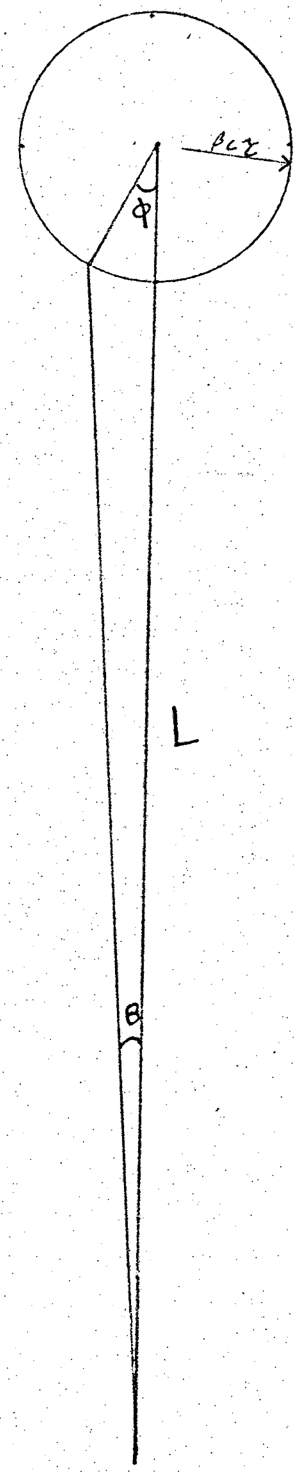
A more exact treatment, taking account of the non-thermal nature of the electron energy distribution, and of the various pitch angles between the electrons and the magnetic field, yields the relation

$$B = 2.44 \times 10^{-8} \theta^4 S_m^{-2} \nu_m^5 (1 + z)^{-1}$$

for the magnetic field, B in gauss, θ the angular size in seconds of arc, ν_m the frequency of peak emission in megahertz, and z the source redshift. This equation gives a direct measurement of the magnetic field in a synchrotron emission source. (See Clark, <u>et al</u>., 1968, <u>Ap. J.</u>, 153, 705).

E. The Variable Synchrotron Sources

Consider a source expanding with speed βc, starting at $t = o$. At time t it will be a shell of size βct. Radiation emitted at angle ϕ will arrive at the earth at epoch



$$T = t + \frac{L - \beta ct \cos \phi}{c}$$

and it will appear to come from an angle θ removed from the center,

$$\theta \approx \frac{\beta ct \sin \phi}{L}$$

The radiation arriving at a given epoch T thus arrives at angles θ

$$\theta = \frac{\beta c}{L} \left(T - \frac{L}{c}\right) \frac{\sin \phi}{1 - \beta \cos \phi}$$

The maximum value of θ occurs for some ϕ_o, which satisfies

$$\cos \phi_o = \beta$$

and has a maximum value

$$\theta_o = \frac{\beta c}{L} \left(T - \frac{L}{c}\right) \frac{1}{\sqrt{1 - \beta^2}}$$

Thus, the apparent expansion rate for $\beta \approx 1$ is higher than c by the factor $1/\sqrt{1-\beta}$.

(See Gubbay *et al*. 1969, *Nature*, **224**, 1094.)

Reference: Whitney *et al*. 1971, *Science*, 173, 225.