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A Spectrographic Interferometer

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The paper includes a description of the principal novelties of a swept-frequency interferometer operating between 7.6 and 41 MHz at the High Altitude Observatory in Boulder, Colo., since July 1959. Records of Jupiter's decametric radio emission, and of a solar harmonic type III burst are included, with a cursory description of the corner-reflector antenna system used to feed the receiver. The receiver employs unique "minimum detection" circuits to reduce the deleterious effects of telecommunications stations on detection of the weak astronomical signals of interest to us. For interferometry, the receiver uses an inversion circuit to present both negative and positive fringes as darkening on the final record, and to sharpen fringe crossovers.

As part of a program of low-frequency radio astronomy studies, the High Altitude Observatory decided some years ago to construct a swept-frequency interferometer. The principal scientific problems attacked with this instrument, (see figs. 1 a, b, and c), in operation since July 1959, have been studies of the nonthermal emission by the sun and the planet Jupiter and of the ionospheric refraction, absorption, and scintillation effects in radio stars. Data on solar emission observed with this equipment are summarized monthly in NBS–CRPL F-Series, Part B, Solar Geophysical Data. Studies on radio star scintillation effects have appeared in papers by Warwick [1964a] and Singleton [1964]. Finally Jupiter researches with this equipment have been summarized, most recently by Warwick [1964b].

Since we contemplated construction of only a single receiver we found it necessary to combine the dynamic range capabilities of a standard radio spectrograph with the position-finding capabilities of the swept-frequency spectrograph described by Wild and Sheridan [1958]. The combination would in any event prove useful in separating the positional shifts in solar emission from the complex dynamic spectral details occurring during major events.

The enormous abundance of communications signals in the frequency range below 30 MHz had to be coped with from the outset, and led us to

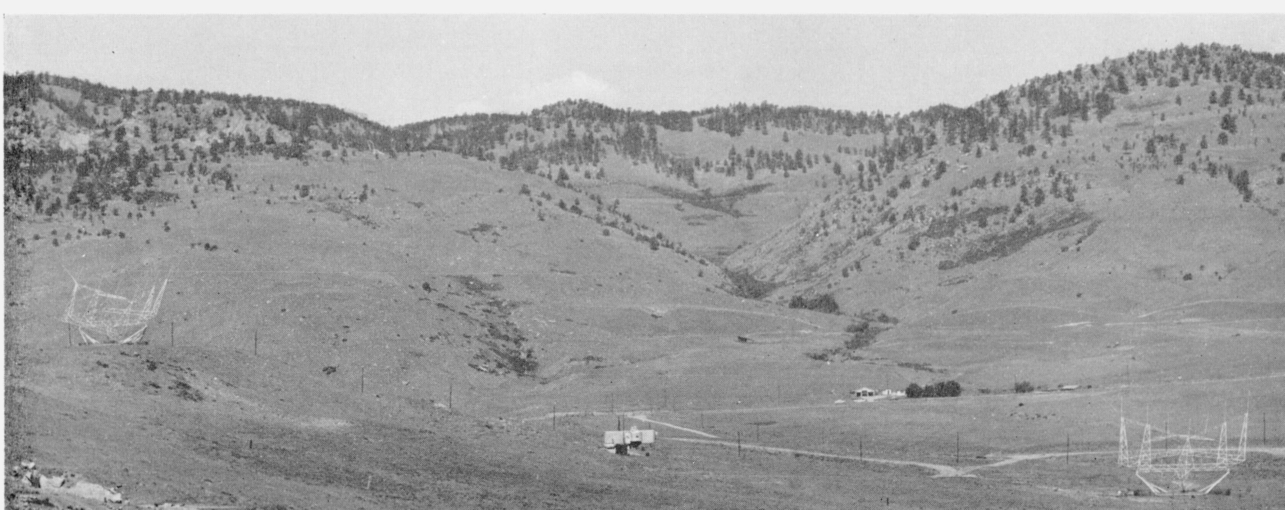

FIGURE 1a. *The two corner-reflector antennas are at the far right and left of the illustration.*

They are trihedral corners, shown here pointed generally toward the camera at an elevation angle of about 45 deg to the horizon. Their dimensions correspond to an effective capture area of about 500 m² per unit. The signals are combined in the receiver halfway between. Spacing of the antennas is 263 m along a baseline depressed 8 deg below the orizontal at an azimuth of 41 deg east of north. (View toward the west.)

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FIGURE 1b. *Another view of the interferometer, showing side views of the corner-reflectors.*
(View toward the south.)

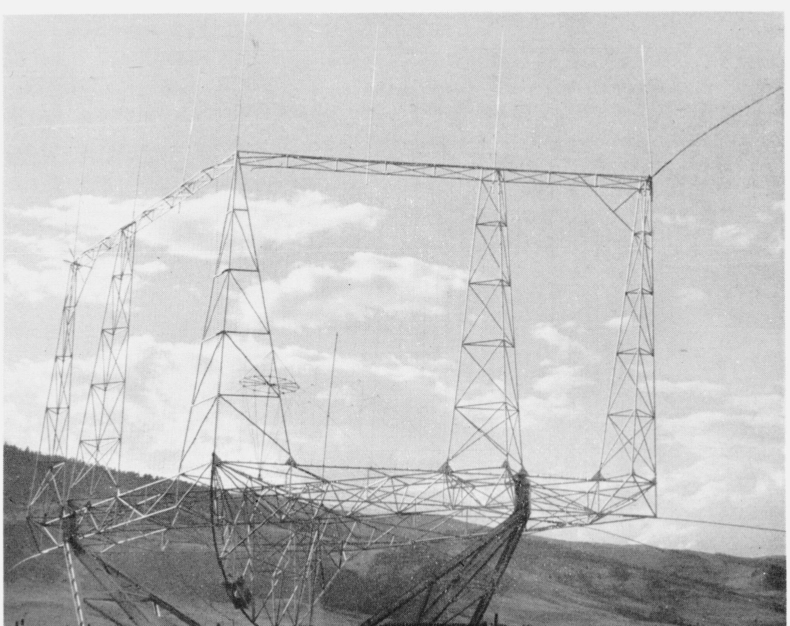

FIGURE 1c. *Detail of the south western corner reflector.*

The photograph shows the three mesh-systems that define the reflecting planes, and also the two broadband feeds. These are expanded (conical) monopoles, mounted parallel to one another and to the vertex of the dihedral angle formed by the vertical reflecting planes. These are fully steerable units with dimensions approximately 110 ft wide by 61 ft high above the reflecting ground plane.

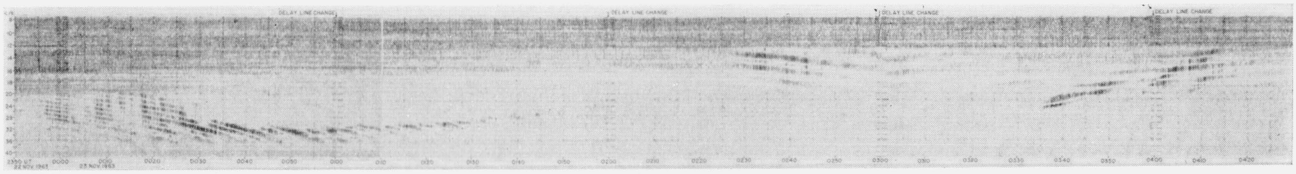

FIGURE 1d. *A record of Jupiter's decametric radio emission (see text), in the low-frequency range from about 0220 UT to 0420 UT.*

The record exhibits an imbalance in the negative fringe inversion, so that alternate fringes appear relatively dark. The record shows characteristic drifting spectral features in times earlier than (<0200 UT) and later than (>0200 UT) the time when Jupiter's magnetic dipole moment is tipped towards the earth (see reference to Jupiter given in text).

a unique combination of phase-switch and synchronous detection circuits of the "minimum detection" type [Lee, 1957]. This circuitry permits the integrating and recording circuits to accept information only from the "holes" between stations as the receiver sweeps in frequency. The output circuits also contain a unique inversion scheme for transforming negative interference fringes to positive fringes. Unlike Wild's and Sheridan's interferometer, ours displays both positive and negative fringes as darkening on the final intensity modulated display, with fringes of one-quarter, three-quarter, one and one-quarter, etc., order appearing as narrow white bands. Figure 1d illustrates the final result, in this case a record of Jupiter's decametric emission on 22/23 November 1963 from 2350 UT to 0430 UT. The communications bands are reinjected to provide us with frequency, time, and ionospheric indicators for about 22 sec out of each 5 min interval. This record demonstrates that the minimum detection circuits, in combination with the phase-switching, swept-frequency interferometer, can operate effectively in bands normally unused in radio astronomy because of severe communications interference. The record also shows how the effective maximum usable frequency (called "MUFE" by us) decreases rapidly through the hours around sunset.

Figure 2 illustrates solar emission observed with this equipment down to 8 MHz on 22 June 1961 at 1804 UT. A continuum storm was then in progress (see CRPL F-Series, Part B, November 1961 for a description of this kind of solar emission as observed with our equipment) and, as is oftentimes the case, was accompanied by many type III bursts extending to the lower limit of the receiver. The particular event illustrated in figure 2 is of importance in showing both the fundamental and second harmonic of the burst at 8 MHz, implying that on this occasion the fundamental reached at least the 4 MHz plasma level in the corona.

Antenna phase-switching is accomplished in this receiver at the input tuning stage of the RF amplifiers. One antenna is coupled through a fixed coupling coil, and the other, to the center tap of a coil whose ends are alternately grounded by diodes during successive halves of the switch cycle. The switch rate is 1000 hertz.

The tuning is linear in each octave, swept in 0.65 sec, once each 1.30 sec. To achieve linear tuning, the receiver employs cam-driven ferrite-core inductances in the oscillators and two or three tuned

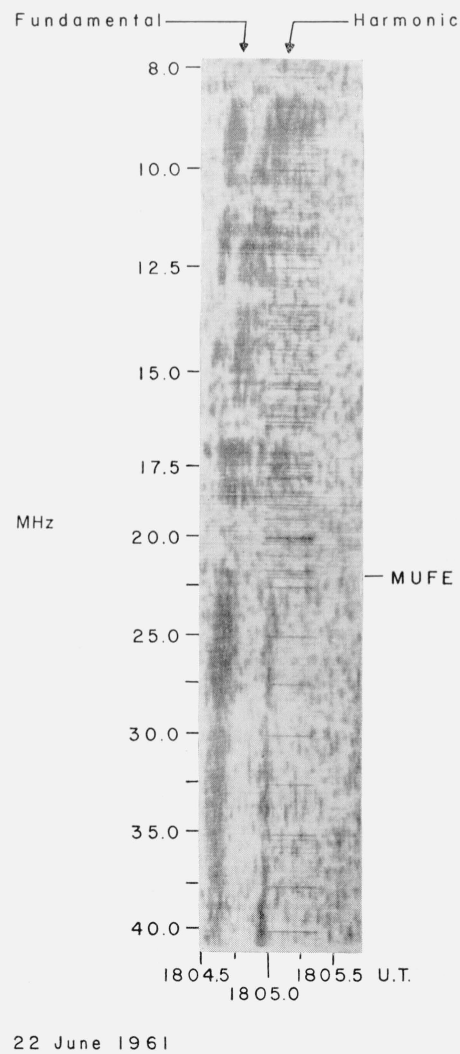

FIGURE 2. *Type III fundamental and second harmonic at 8 MHz.*

This record was made originally on the same time-frequency scales as figure 1. The frequency scale has been compressed by a photographic process to emphasize the harmonic structure of the type III burst.

stages (in the low and high frequency octaves respectively) plus, of course, split-stator condensers which carry the bulk of the tuning. The cams may be cut to present optimum matching of receiver to antennas at each frequency. The receiver uses pentode RF stages, rather than the cascode or wide-band amplifiers often found in swept-frequency receivers. Noise figure is, of course, a relatively minor problem here, and our receivers achieve values of the order of 3 dB without difficulty. Cross-modulation and overload effects are far more important, especially for a receiver designed, as this one is, to observe weak sources such as Cygnus A and Jupiter. These effects lead us to reject cascode and broadbanded circuits at the RF level.

The first IF is 5.98 MHz; we have found that despite the desirability of narrowbanding the IF stages as much as possible, the narrowest bandwidth we can use effectively is 16 kilohertz, which is defined by a commercial mechanical filter operating in the second IF, 455 kilohertz. The final IF tuned stage is followed by an infinite impedance detector, V4A in figure 3. Increasing signal strength causes this detector output to go positive. The offset to −150 V is required by our facsimile method of recording, and not for the operation of the detector. Tube V4B is a cathode follower used to obtain a low driving impedance for the "minimum detection" circuits that follow.

There are two of these minimum detector circuits, operated alternately by the switch generator, but for the moment let us consider the operation of only the basic minimum detector shown in figure 3. The output of the cathode follower V4B is connected through R3, and assuming that levels are stabilized, current will flow through D3, through N1, and then through R17 to the +150 V supply. Tube V2A is biased beyond cutoff under these conditions so that no current flows through it. Since D3 is conducting, the RC circuit R9, C11 will charge to a level determined by the voltage drops across R3, N1, and R17. If the output of detector V4 decreases (goes in a negative direction), then D3 will remain closed, and the voltage at C11 will follow the change in the negative direction, with a time constant determined by R3, R9, and C11. Until the voltage at C11 is stabilized at the new level, there will be a current flow in R9, and this current will be added to the normal current flow in R3, increasing the voltage drop across it.

Assume now that a small increase in signal causes the detector voltage to go in a positive direction. There will then be a current in the opposite direction in R9. Because R17 is connected to a rather high voltage, current through it will remain essentially constant. This means that then the current flowing in R9 is subtracted from the current flowing in R3. If the increase in signal is large enough, all the current flowing in R17 will flow in R9, and none of it in R3. Under these conditions, D3 will open, and C11 will charge in a positive direction at a rate limited by R17, regardless of how large the signal is.

Let us assume that previous experience has shown us that a signal greater than a certain amplitude is likely to be a radio station rather than the "noise signal" we seek. Keep in mind that we tune the receiver rapidly, so that tuning across a station causes a positive pulse at the detector. We can set the bias for V2A so that it conducts whenever this certain amplitude is reached. Then, the current through R17 will flow through V2A, the voltage across N1 will be too low to sustain ionization, and N1 will extinguish. This disconnects R17 from R9. Since D3 was already open, R9 and C11 are completely disconnected from any incoming signals, and the voltage level at C11, and therefore at the cathode of V1A remains constant until the radio station is tuned out and the normal noise signal returns. Then V2A is cut off, permitting N1 to conduct. This in turn will cause current to flow through D3 and R3, once again connecting C11 into the circuit through R9.

Referring now to figure 4, we show a practical means of biasing V2A, by the use of R1, R5, R19, and P1. The "punchout level" control adjusts the bias on V2A beyond cutoff, and thus determines the

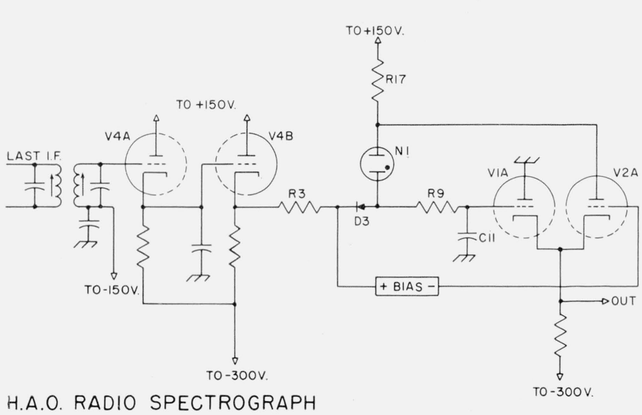

FIGURE 3 *Infinite impedance detector and basic minimum detector.*

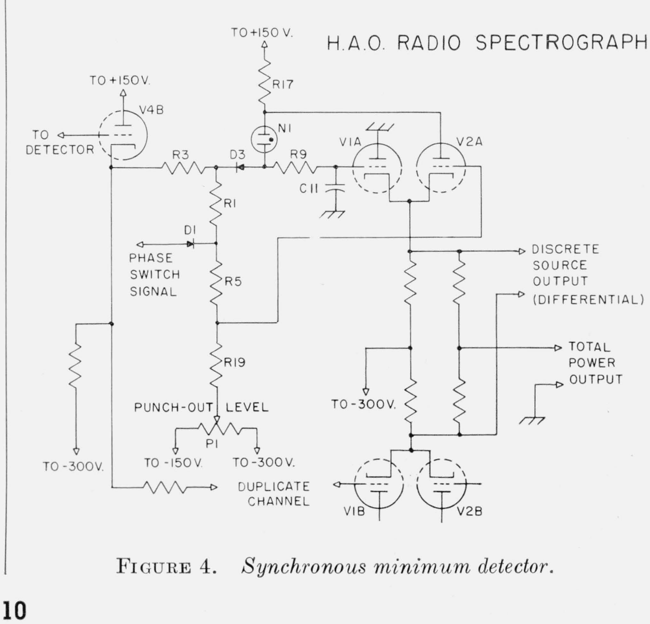

FIGURE 4. *Synchronous minimum detector.*

amplitude of the signal required to cause V2A to conduct. We call this conduction of V2A "punch-out," although disconnect would probably be a better term. It should be kept in mind that the voltage at the cathode of V2A is set by the average noise signal. This means that the signal required for punchout will be a specific amplitude above this average level. The specific amplitude required is determined by the setting of P1. Another factor to keep in mind is that punchout will take place only if the rate of change in amplitude is fast enough that C11 cannot follow the change, and thus prevent D3 from opening and V2A from conducting.

Since we have a means for disconnecting the minimum detector during the time a radio station is present in the signal channel, let us now develop a method for using this same disconnect or punchout circuit for phase switching. This will be done in order to use two of the minimum detectors in a phase-switched interferometer.

If we connect a large positive-going phase switch signal to the anode of D1, the effect will be the same as though the receiver suddenly tuned onto a station. That is, the cathode of D3 will be driven positive, and D3 will open. Also V2A will conduct, causing N1 to extinguish, thus disconnecting R9 and C11 for the duration of positive half cycle of the switch signal.

Now a duplicate minimum detector channel can be added as shown. Its phase switch signal should be the other half of a push-pull signal. This means that the duplicate channel will also be disconnected by a positive-going phase switch signal, but the two channels will operate on alternate half cycles of the phase switch reference signal. Since this is the same reference signal (1000 Hz) which drives the antenna diodes, we now have a synchronous detector. The phase sensitive output is taken as the voltage difference between the cathodes of V1A and V1B. Total power output may be taken as the sum or average voltage of these two cathodes.

The average level of the two minimum detectors develops an AGC voltage which controls IF gain to present a constant "minimum" level to the detectors. This means that the gain of the receiver is controlled by the galactic noise background, or the source being observed if it is strong enough to predominate.

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