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A HISTORICAL REVIEW OF THE DOPPLER SPECTRUM TRACKER DEVELOPED FOR THE FIRST CANADIAN LIGHTWEIGHT DOPPLER RADAR

by

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FOREWORD

A Doppler Spectrum Tracker for the first Canadian Lightweight Doppler Radar was developed by the Defence Research Telecommunications Establishment (DRTE), a major component of the Defence Research Board, Department of National Defence, Canada. DRTE became the Communications Research Centre (CRC) by transfer to the new Department of Communications, Canada, in July 1969.

On completion of this project, in 1959, the commercial exploitation and development of the results of the DRB research was undertaken by the Canadian Marconi Company. The system was used successfully in the production models of the AN/APN 147 and the CMA 623 radars, the first of a series of lightweight airborne doppler navigation systems developed in Canada.

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ABSTRACT

An historical account of a DRB developed doppler spectrum tracker for the first Canadian lightweight doppler radar is provided for archival purposes.

A system for tracking the doppler frequency spectrum from an airborne navigation radar is described. The tracker provides a continuous analogue output for ground speeds between 50 and 1,000 knots. Integrated ground speed is also provided in digital form. The precision of both measurements is within one-half per cent over a complete environmental range of operation. The system was used successfully in the production models of the AN/APN 147 and the CMA 623 radars. These radars were the first of a series of lightweight airborne doppler navigation systems developed in Canada.

INTRODUCTION

There is a need to provide an historical account for archival purposes of the DRB development of a doppler spectrum tracker for the first Canadian lightweight doppler radar. The report which follows provides such an account and the statements in the document should be considered in this context. Among the systems investigated for this purpose were an all-electronic version of the original British-developed Green Satin tracker, (actually a two-channel spectrum analyser), at least two heterodyne systems, and a zero-frequency discriminator. Except for the first, all schemes had intrinsic drawbacks. The heterodyne systems imposed too-stringent requirements on the long term stability of high frequency oscillators and filters; the zero-frequency discriminator suffered from lack of a broad band 90° phase shifter; the two-channel spectrum analyser was successful but required a matched set of precision oscillators and low frequency amplifiers. Since the latter system suffered only from a multiplicity of precision parts it was decided to simplify the design by using only one precision oscillator and one simple low-pass amplifier. Such a combination could be made to do the same work as a matched pair by the use of phase lock techniques, and this scheme was decided upon.

TRACKING THE SPECTRUM

A brief review of the tracker problem will be of assistance at this point. The problem is to locate the energy centre of a Gaussian distribution of noise (hereinafter called the doppler spectrum). In an aircraft, the centre frequency of the doppler spectrum, or as it is commonly called, the doppler frequency, is directly proportional to ground speed, and for this system lies between 0 and 20 kHz for subsonic speeds when present radar frequencies and antenna configurations are used. The output from the tracker is translated into a shaft angle that is directly proportional to the aircraft ground speed. This angle can then be used to operate pointers, or to control other shaft motions in computers.

THE HETERODYNE SYSTEMS

A block diagram of the first heterodyne system is shown in Figure 1. An oscillator signal tunable between 21 and 41 kHz is mixed with the doppler signal and the resulting output is passed through a high-pass filter that has a low frequency cut-off of 41 kHz. The output of this filter is then fed to two narrow filters that are placed side by side in the spectrum and whose crossover point is 42 kHz. The signals from the filters are detected and a comparison of the two outputs provides an error signal in the servo loop until

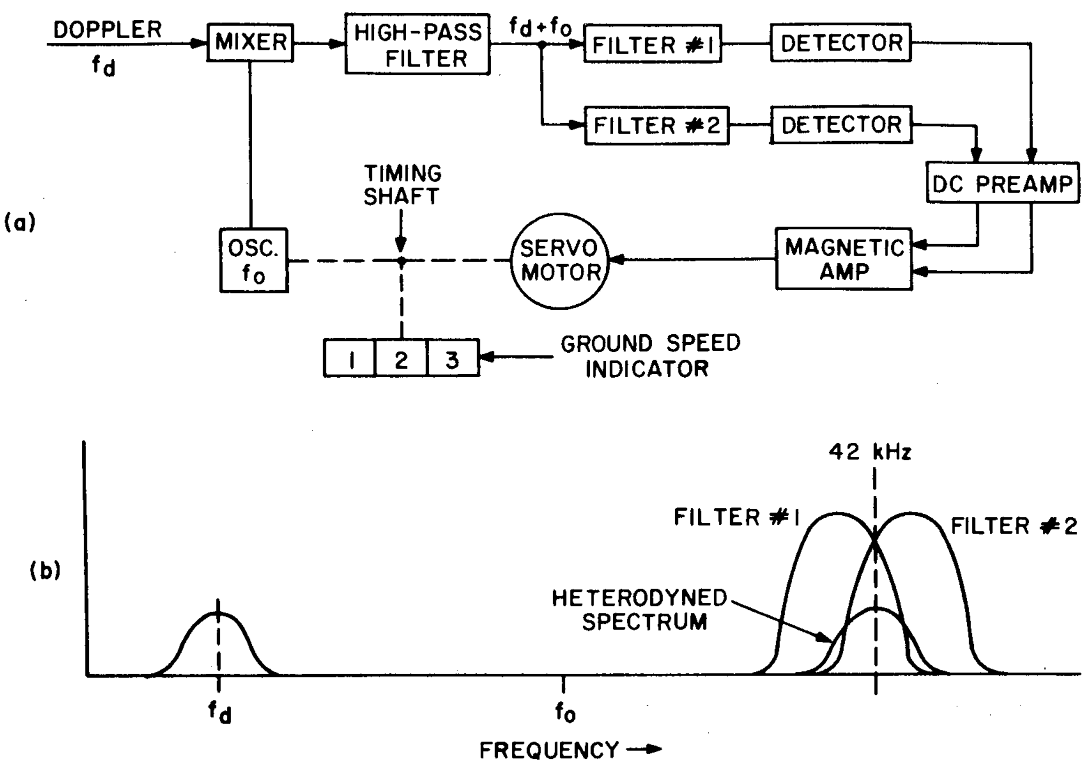

Fig. 1. Twin-filter discriminator heterodyne system.

each filter receives equal energy from the heterodyne spectrum. This occurs at 42 kHz. At this stage the oscillator will be tunned to (42 - fd) kHz, where fd is the original doppler frequency. Since the oscillator tunes linearly in frequency for uniform rotation of the tuning shaft, the angular position of the tuning shaft is an indication of the aircraft ground speed.

It was difficult, in this system, to keep the crossover of the filters at 42 kHz. The doppler was to be measured to 0.1 per cent accuracy and this meant a frequency error of no more than 2 to 3 Hertz, in the low-speed case. It was felt that it was impossible to maintain crossover accuracy within these limits with ordinary LC filters. The modified Wein bridge-type oscillator developed for this circuit appeared to have adequate stability, but the scheme was abandoned because of the filter problem.

The second heterodyne system is shown in Figures 2(a) and (b). In this case a crystal discriminator was used instead of a pair of filters and the oscillator was tuned from 80 to 100 kHz. The stability requirement of 2 to 3 Hertz for a given tuning shaft position was too stringent for the oscillator however, and this scheme was also abandoned even though the crystal discriminator had more than adequate frequency stability.

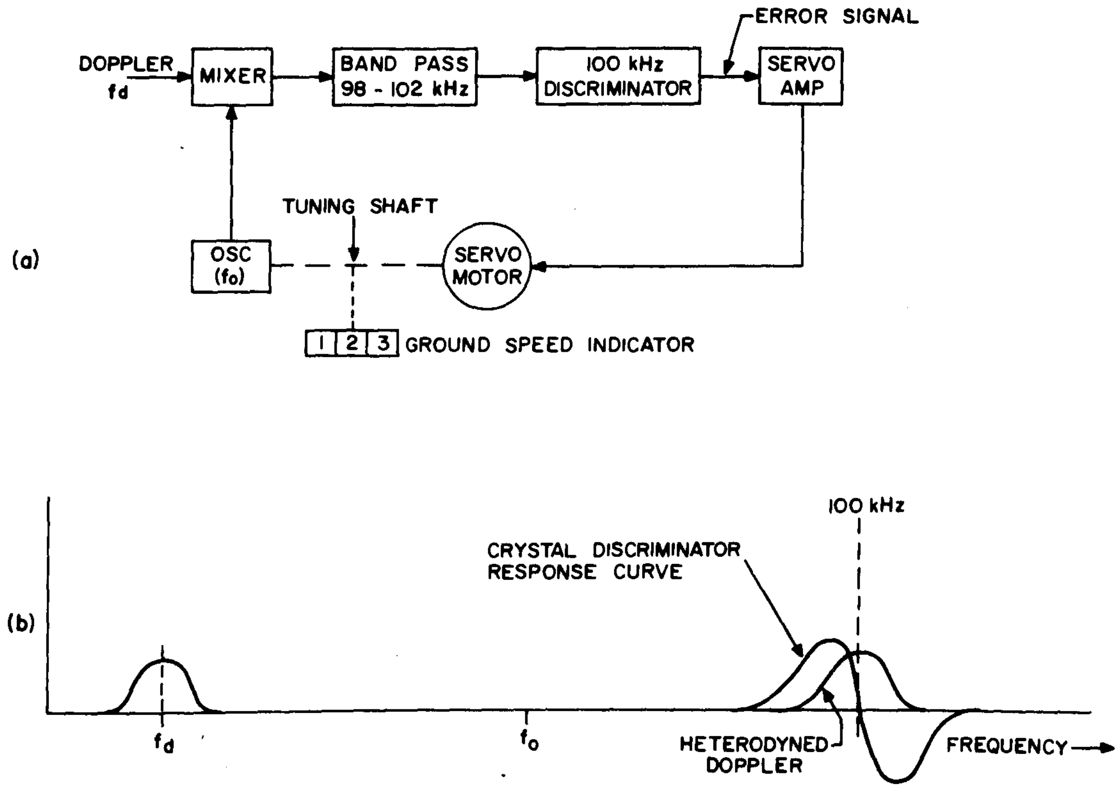

Fig. 2. Crystal-discriminator heterodyne tracker.

THE TWO-CHANNEL SPECTRUM ANALYSER

A block diagram of the modified version of the Green Satin tracker, as built in the DRTE Electronics Laboratory, is shown in Figure 3. Oscillators 1 and 2 are precision types which tune linearly in frequency with uniform rotation of the common tuning shaft. They are separated in frequency by about 15 per cent. In the original British system a high speed rotating shaft with two toothed wheels coupled to magnetic pickups took the place of these two precision oscillators and a rate generator on the high speed shaft was used to provide a voltage analogue of the frequency.

For simplicity, consider a single oscillator and mixer. The doppler signal is mixed with the oscillator output and the resulting signal is passed through a low pass filter whose high frequency cut-off is a few hundred Hertz (in the present case 300 Hz). The low frequencies are then amplified and detected with an integrating condenser.

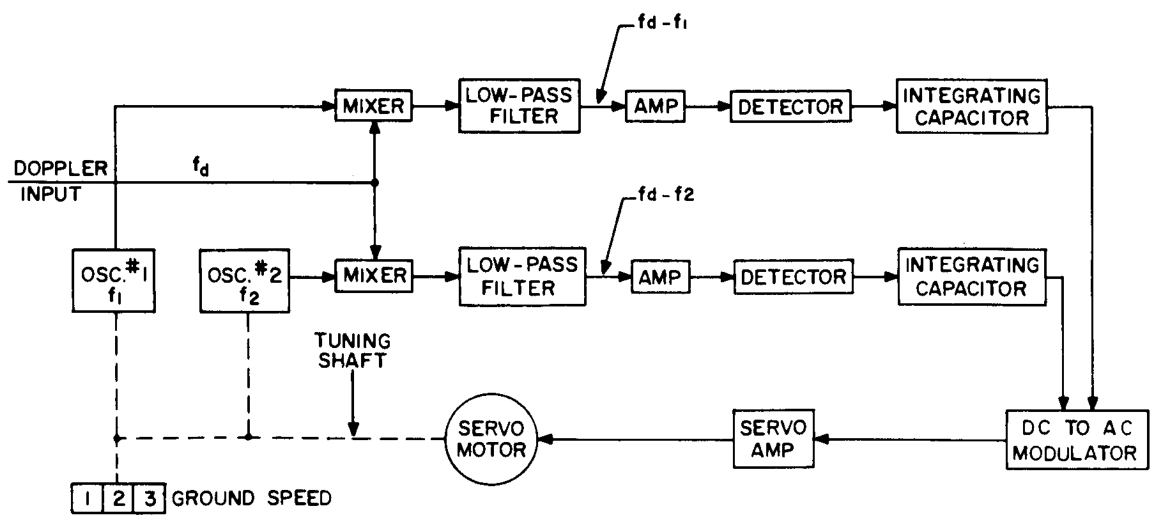

Fig. 3. Two-channel spectrum-analyser tracker.

Figure 4 represents graphically the state of affairs when the oscillator is tuned to f_0. Any frequencies presented to the mixer and that lie between f_L and f_h will beat with f_0 to generate difference components lower than 300 Hz. These components will pass to the detector and provide DC signals on the integrating capacitor that are proportional to their magnitude. Clearly, then, the combination of a tunable oscillator, a mixer, and a low pass filter represents a spectral 'window' whose width is twice the width of the low pass filter and that can scan a frequency spectrum within the tuning range of the oscillator. The complete tracker uses two of these windows, spaced about 15 per cent in frequency as mentioned earlier. Operation of the tracker is depicted in Figure 5 where S represents the energy vs frequency curve of the spectrum to be measured, f_d is the doppler center frequency, and f_1 and f_2 represent the frequencies of the two oscillators which, with their respective mixers, filters, amplifiers and detectors, constitute channel 1 and channel 2 respectively. Under the conditions shown, channel 2 has more energy than channel 1 and there will be a differential DC error signal between the two integrating capacitors. This DC error can be used to operate the servo motor

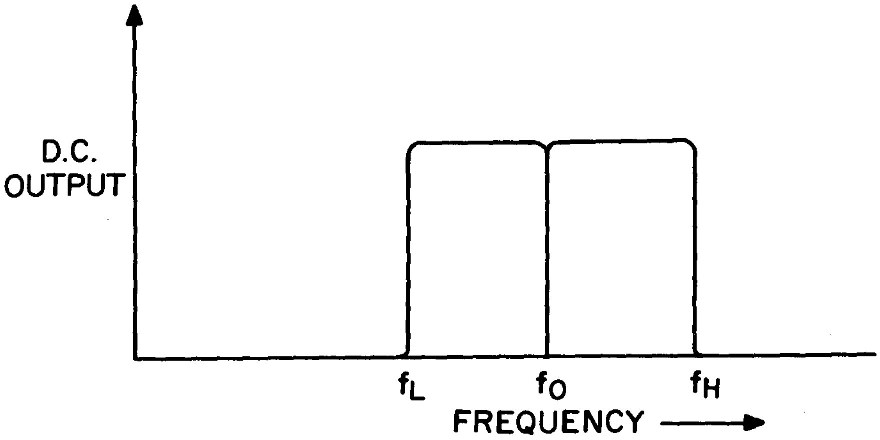

Fig. 4. Single Channel Spectrum Analyser-Response.

by using a DC to AC modulator and a power amplifier. The motor, being coupled to the tunning shaft, will tune f_1 and f_2 until the energy in each channel is equal and the DC error will vanish. Since f_1 and f_2 will be equidistant from f_d, their mean frequency

$$\frac{f_1 + f_2}{2} = f_c$$

will equal f_d. It is obvious that the servo loop has 'sense' since when f_c is greater than f_d it produces a DC error that is opposite in polarity from the case where f_c is less than f_d.

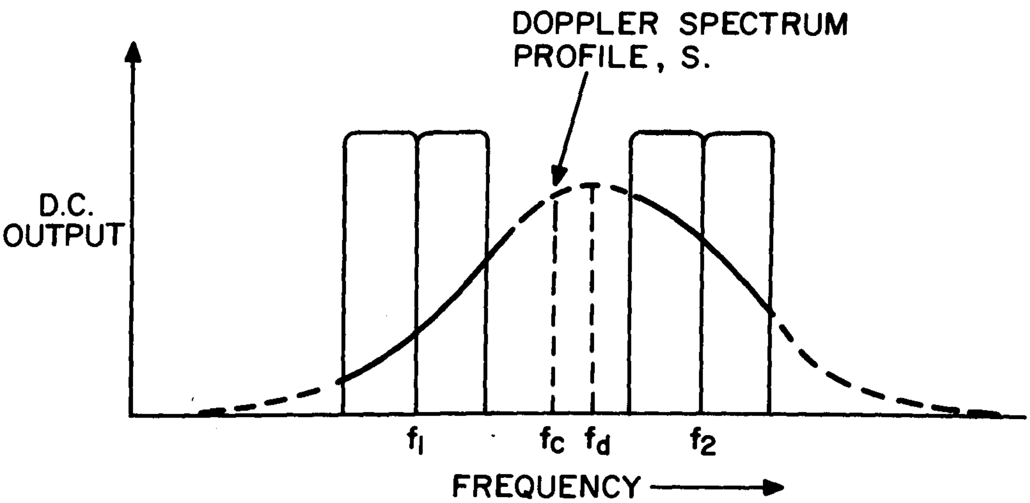

Fig. 5. Two-channel spectrum-analysier.

THE PHASE-LOCK SPECTRUM ANALYSER

Since the tracker will position itself until both integrating capacitors have the same DC voltage, it is important that each channel of the tracker have the same gain and filter width so that equal capacitor voltages truly represent equal signals at the inputs to the filters. Also, each oscillator must maintain accuracy in frequency vs tuning shaft position, otherwise the shaft position will be in error when $f_c = f_d$.

For these reasons, it was decided to time share one precision oscillator between f_1 and f_2, and to use a single mixer, low pass filter, amplifier and synchronous detection. There would be two integrating capacitors with the detector being linked through a commutator to these two capacitors in synchronism with the generation of f_1 and f_2. Thus capacitor C_1 would receive and integrate the DC output when the spectral window was at f_1, similarly C_2 would receive and integrate the DC output when the window was at f_2. The time constant during detection can be set arbitrarily by placing a suitable shunt resistor on the detector; this leaves the capacitors unloaded during the half-period when they are not connected to the detector. (Actually, the condensers are loaded at all times by the DC to AC modulator in the servo loop, but the input impedance of this device is high enough to prevent a serious loading problem).

The basic circuit is shown in Figure 6. The doppler input is mixed with the output of a tunable oscillator and the output of the mixer feeds a low pass filter, amplifier, and detector. The detector can be connected to either of two integrating capacitors C_1 and C_2 by the 5 Hz driver which operates the switches S and S_2 in synchronism. The tunable oscillator is a relaxation type that is very stable and in which there is a linear relation between frequency and tuning voltage. The tuning voltage is derived from the slider of a precision potentiometer R_s, and the current to this potentiometer is controlled

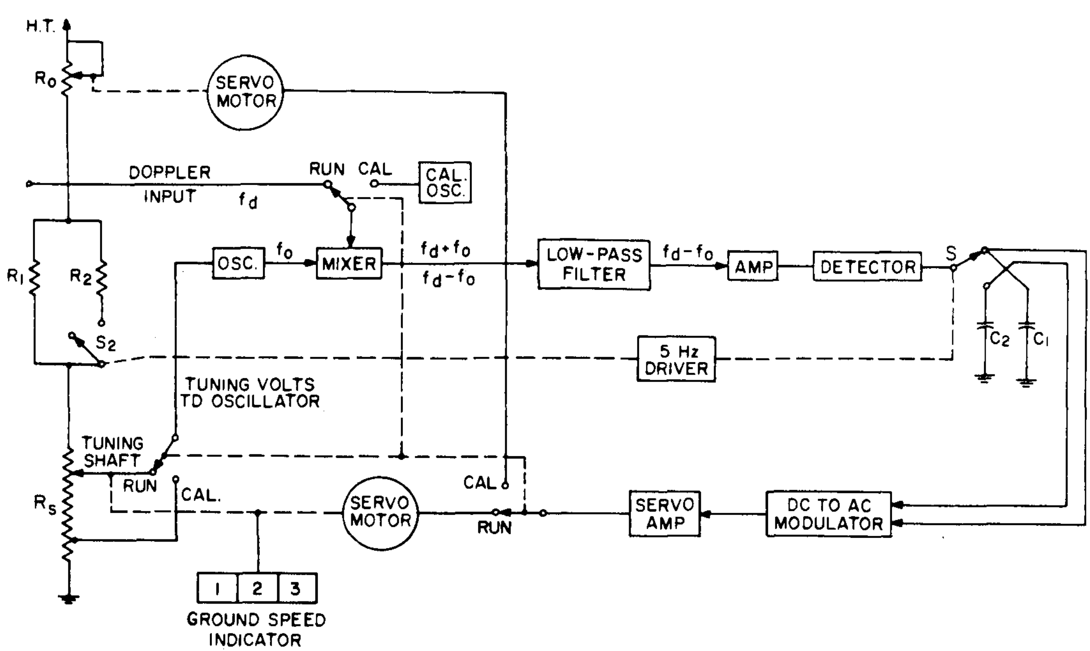

Fig. 6. Phase-lock spectrum-analysis tracker.

by the resistors R_0, R_1, R_2, and R_s. When switch S_2 is closed there is a current change of +15% in R_s. Referring to Figure 5 and Figure 6, it is obvious that, with S_2 open, the energy in the window at f_1 is being integrated on C_1 and with S_2 closed the energy in the window at f_2 is integrated on C_2. For the situation depicted in Figure 5 there is an error signal in the servo loop. This error signal causes the tuning motor to reposition the slider on the potentiometer R_s until f_1 and f_2 are equidistant from f_d as in the previous arrangement. As indicated, the tuning shaft is mechanically coupled to a veeder-type dial that indicates the ground speed of the aircraft.

CALIBRATION

The relation between the centre frequency of the doppler spectrum and the ground speed of the aircraft can be determined from knowledge of the frequency of the radar transmitter and the geometry of the antenna system with respect to the ground. The proper mean frequency of the tracking oscillator at any ground speed is then known and the potentiometer R_s can have its mean current adjusted to give the correct oscillator frequency for any reading of the ground speed indicator. This current adjustment is provided by the variable potentiometer R_0. It is interesting to note that the tracker can calibrate itself against a standard frequency f_s which is coupled to the mixer instead of a spectrum. Assume a tap on R_s corresponding to the ground speed which would normally supply a doppler spectrum centered on f_s. Then, if f_c, the mean frequency of the oscillator, is equal to f_s, there will be no error signal in the tracker loop, but if f_c is not equal to f_s an error will exist in the loop and this can be used to drive another servo motor which positions R_0 until f_c equals f_s. This self-calibration is very attractive since it requires only a stable single frequency oscillator that is not difficult to construct, a change-over relay, and an extra motor. This feature has been incorporated into the present tracker.

Figure 7 is a schematic diagram of the mixer, amplifier, low pass filter and detector. The amplifier is a remote cut-off pentode. An AGC voltage is supplied to the grid of this stage from a voltage doubler that rectifies

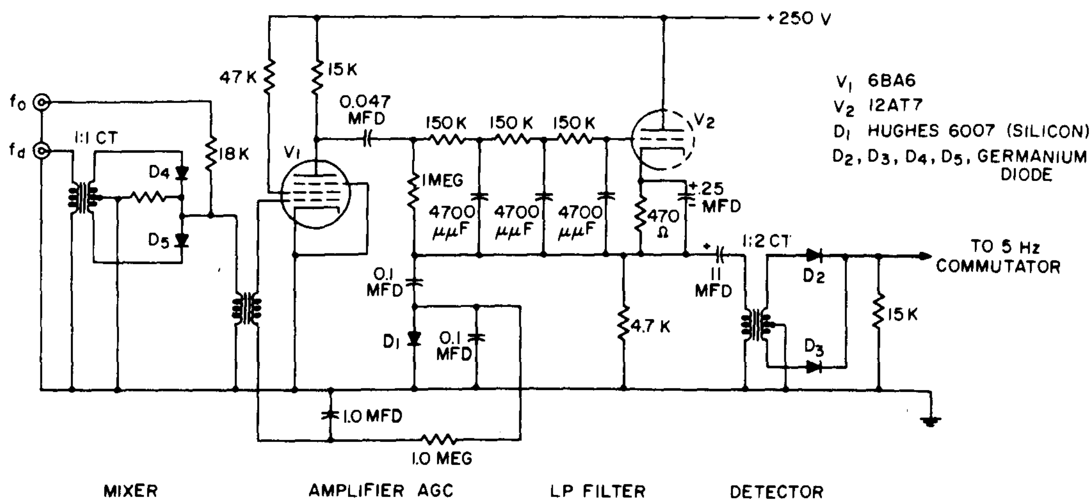

Fig. 7. Mixer, AGC amplifier, low-pass filter, detector.

the low frequency output of the filter. The low-pass filter is an active feedback type that makes the pass band quite square and provides a steep cut-off characteristic. The detector is a full wave type, which allows the time-constant to be set low. By so doing, a better average DC level for the noise is achieved, since a long time constant changes the detector to a peak reading type.

The oscillator is shown schematically in Figure 8. Briefly, it is a pair of Miller integrators that are triggered on alternate half cycles by grid-to-suppressor coupling. This variation of so-called phantastron circuits was developed in this laboratory and has proven to be quite satisfactory. The purpose of the bias potentiometer in the cathode circuit of the two pentodes is to ensure that the frequency vs control voltage curve goes through the origin. This is accomplished by observing the waveform at the grid of both pentodes, and adjusting the cathode bias resistor until the grid voltage falls to zero volts DC at the beginning of the Miller run-down. It has not been found necessary to readjust this bias during several hundred hours of operation of the oscillator, as long as the same pentodes are in the circuit. Replacement of a pentode may require a resetting of the bias.

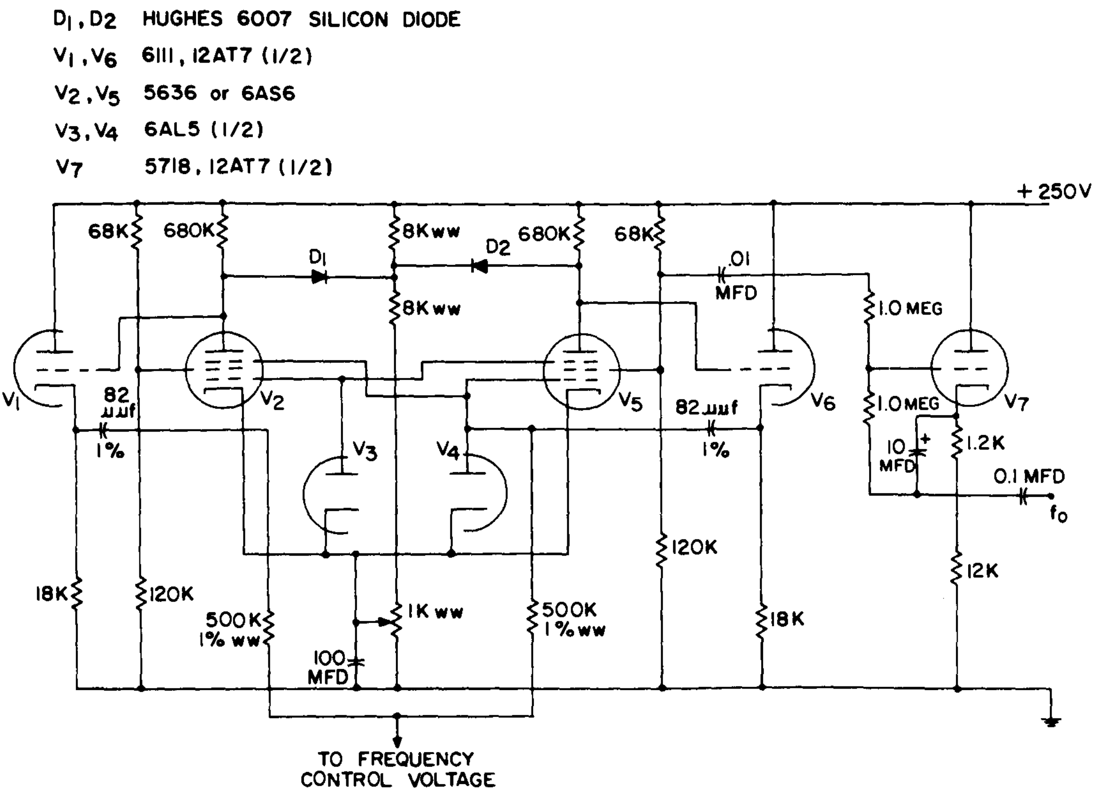

Fig. 8. Tracking oscillator.

CONCLUSION

Several models of this tracker have been built in the laboratory and have been flight tested. Performance has been adequate in all cases. When checked against a calibrating sine-wave, the day-to-day variation in calibration is less than 0.5 per cent with no adjustment of the trimming resistor R_0. The advantages of the phase-lock tracker are:-

(i) It requires only one tracking oscillator.

(ii) With self-calibration, the long-term stability of the tracking oscillator will be as good as the long-term stability of the calibrating oscillator.

(iii) The mixer, low pass filter, amplifier and detector are common to both spectral windows, so the possibility of an error signal in the loop due to unbalance in the two channels is eliminated.

ACKNOWLEDGEMENT

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