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The AEROVOX Research Worker

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Automatic Frequency Control

By the Engineering Department, Aerovox Corporation

PRESENT day receivers require very careful tuning in order to obtain the best possible reproduction of speech and music. Due to the sharpness of the tuned circuits, a mistuning of a few kilocycles will result in annoying distortion. The effect is made worse by the a.v.c. circuits which keep the volume approximately constant when the receiver is detuned. In fact, the adjustment for loudest sound is usually several kilocycles off resonance. In spite of the various tuning aids, such as the tuning meter, magic eye or dimming light, the public appears either incapable or unwilling to take the proper care in tuning with the resulting mediocre reception. It is therefore in the interest of the radio industry to provide some form of automatic tuning which will make it impossible for the listener to have his receiver operate on the edge of the resonance curve.

There are perhaps mechanical ways of obtaining the desired result but to the radio engineer the electronic methods are much more desirable. The various circuits devised for the purpose all aim to solve the problem in a similar manner. As soon as the listener has tuned his receiver to within a few kilocycles of the desired signal, the a.f.c. circuit shifts the tuning electrically to within a kilocycle of the correct adjustment. In demonstrations it has been shown that such a receiver when tuned to a frequency exactly midway between two stations 10 kc. apart, will select the louder one of the two. Also, when both stations come in equally strong, at the first occasion when the modulation of the one carrier makes it become stronger than the other the circuit will adjust itself for this station and remain so.

The advantage of such an arrangement is easily seen, instead of occupying a width of 15 kc. on the dial, about

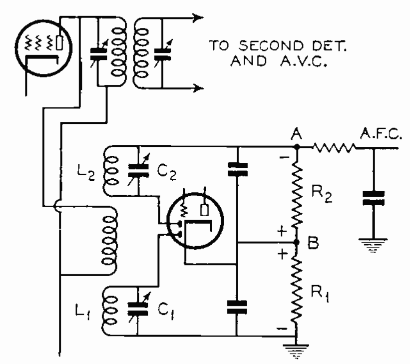

Fig. 1

3 kc. of it usable, the same station will now be received over a fairly broad band but abruptly dropped at the edges. The system can be used to advantage in connection with automatic or remote-control tuning systems since the mechanical device needs to make an approximate adjustment only.

HOW IT WORKS

Assuming that the average receiver is a superheterodyne, the solution is to shift the frequency of the oscillator slightly so as to compensate for the mistuning. This means that the r.f. and detector stages may have to be operated 5 kc. or more off resonance and a rather broad preselector of the band-pass type is desirable.

Two functions have to be performed by the a.f.c. circuit. First, there must be a circuit which discriminates between too high and too low a setting of the dial and which translates the amount of mistuning into control voltages which are positive when the receiver is mistuned in one direction and negative when it is mistuned in the other direction. The control voltage must also be proportional to the amount of mistuning. This part of the circuit is called the "discriminator".

The second functon to be performed is to correct the frequency of the oscillator by means of a circuit which is operated by the control voltage described above. This part of the circuit is called the "corrector".

THE DISCRIMINATOR

S. Y. White, of Loftin-White demonstrated and described the first of the automatic frequency control circuits befor the Radio Club of America in October, 1934. He called them "signal-seeking circuits" and the part which is now generally known as the "discriminator" was called the "director" by him. White's original director is shown diagrammatically in Figure 1. It consisted of a special amplifier tube, driven by a stage of the i.f. amplifier. Its plate circuit contained two transformers with the primaries in parallel. One of the primaries was loosely coupled to two secondaries, while one of the secondaries was tuned to 5 kc. above the intermediate frequency; the other transformer was tuned to 5 kc. below it. Each secondary was connected to a diode and the whole was arranged in such a way that the

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difference between the voltages developed by the two diodes appeared at the point A. The diode circuits employed a tube of the duo-diode-triode type, with the triode section unused.

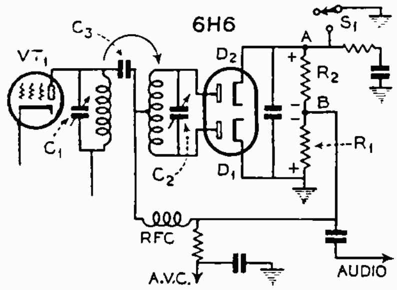

Fig. 2

When the correct frequency is being received, both of the "side circuits" have an equal voltage induced in them and the difference between the voltages across the diode loads is zero. If the incoming frequency is too high for the adjustment of the receiver, there will be more current in the diode circuit, L_1C_1, which is tuned to 5 kc. above the intermediate frequency and the voltage drop across R1 is larger than the drop across R2 with the result that A becomes positive. Similarly, A becomes negative when the incoming signal is too low in frequency. In this system the second detector and a.v.c. circuit require another tube. When it is desired to stop the a.f.c. circuit, the point A can be connected to ground.

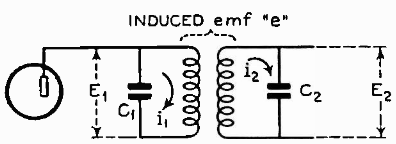

Fig. 3

Since 1934 many improvements have been made in the design of a.f.c. circuits and it is now possible to obtain a.f.c., a.v.c. and detector action all from the same tube and to eliminate the "side circuits", employing a single secondary tuned to the intermediate frequency. Figure 2 shows such a circuit. Its action is based on the phase differences which occur between the voltages across the primary and secondary. In order to understand this, consider Figure 3.

The current, i_1, in passing through the primary of the transformer is lagging 90 degrees behind the voltage, E_1, across the primary. The e.m.f., e, induced in the secondary is again lagging 90 degrees behind the current, i_1, in the primary. Assuming that both transformers are tuned to the applied signal, the current, i_2, in the secondary is in phase with the induced voltage, e, and the voltage, E_2, across the condenser C2 is 90 degrees behind the current, i_2, passing through it. The net result is that the voltage across the condenser C2 is 90 degrees out of phase with the voltage across condenser C1. The phase relations are shown in the vector diagram of Figure 4.

When the applied frequency is too low, the current in the secondary is no longer in phase with the induced e.m.f. The circuit now acts as a condenser (with resistance in series) and the current through the secondary is leading the induced e.m.f. The voltage across the condenser again being 90 degrees behind the current, the vector relations become as in Figure 5. Here the voltage across the secondary is more than 90 degrees out of phase with the voltage across the primary.

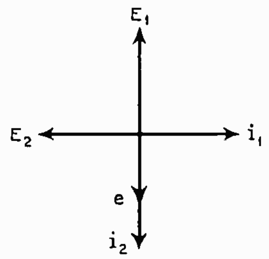

Fig. 4

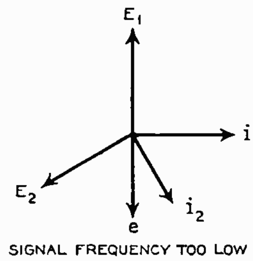

Fig. 5

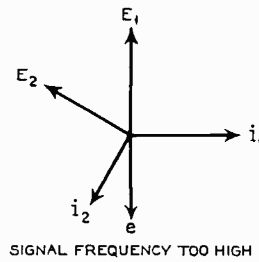

Fig. 6

Similarly, when the applied voltage is too high, the secondary acts as an inductance and the current lags the induced voltage. Under these circumstances the vector relations are as shown in Figure 6. The voltage across the secondary is now less than 90 degrees out of phase with the voltage across the primary.

The circuit of Figure 2 now places the primary of the transformer in series with the centertap of the secondary. The result is that the voltage applied to one diode is equal to the vectorial sum of the voltage across the primary and one half the voltage across the secondary. The voltage applied to the second diode is the vectorial difference between the same two quantities.

The vector diagram of Figure 7 shows these vectorial sums and differences for frequencies which are at, above and below resonance. Note how the voltages applied to diodes D_1 and D_2 vary when the frequency is varied which shows why the voltage applied to the diodes differs when the signal is off resonance. The diodes are again connected so as to obtain the difference between the voltages across the loads R1 and R2.

In order to isolate the secondary from the high voltage, the condenser C3 is needed. The capacitive reactance of this unit is very small for the frequency in question so that it does not alter the phase relations materially. The centertap of the secondary must now be connected to the junction B of R1 and R2 so as to complete the d.c. path for the diode circuit. However, it should not complete the a.c. path so a choke is placed in this lead. The a.c. path is completed through condenser C3 and the primary of the transformer to B plus.

Automatic volume control and audio voltages are taken from the junction B. These can be obtained regardless of the position of Switch S1. Tapped a.v.c. systems can be employed by tapping R1 but care must be taken not to unbalance the circuit for d.c. If R1 is placed in parallel with another resistor, R2 will have to be changed accordingly.

Taking the audio voltage from the same tube has the advantage of simplicity but the quality suffers somewhat. So-called high fidelity requires that a separate detector be employed.

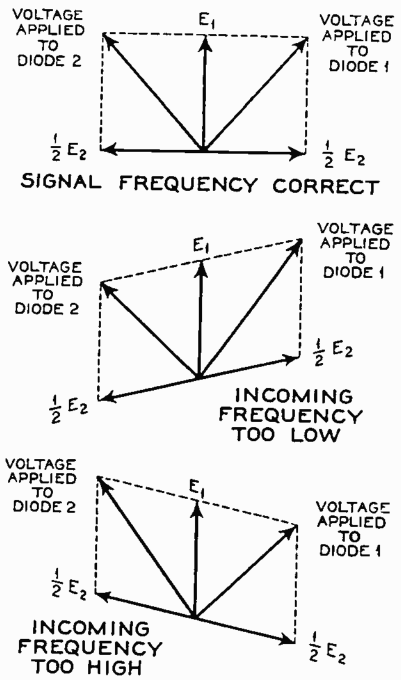

Fig. 7

When this is done, one might couple a third winding to the secondary of the last i.f. transformer but it would be much better to take the signal for the second detector from the grid side of the driver tube VT1. This will eliminate any change of interaction between the a.f.c. circuit and the detector.

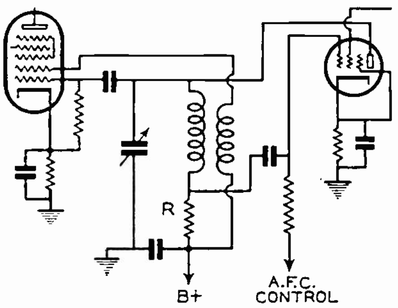

Fig. 8

Both the a.f.c. lead and the a.v.c. lead must pass through a resistance-capacity filter and the time constant of the a.f.c. circuit should be less than that of the a.v.c. circuit. One fortieth of a second is a recommended value for the a.f.c. circuit, one twentieth for the other.

THE CORRECTOR

The corrector usually consists of a control tube, such as a 6C6 or equivalent which is connected across a tuning element of the oscillator tank circuit in such a way as to make the tube equivalent to a condenser or an inductance. The control voltage applied to the grid of the tube varies the amount of this capacity or inductance and therefore changes the tuning.

Figure 8 illustrates how this can be done. The plate circuit of the tube is connected across the oscillator tank circuit. The current through the coil is 90 degrees out of phase with the voltage across the tank circuit which is also the alternating voltage applied to the plate. The current through the small resistor R is in phase with this current and therefore practically 90 degrees out of phase with the voltage across the tank. This voltage is applied to the grid of the tube and causes a current in the plate circuit 90 degrees out of phase with the voltage across the tank which is the voltage across the plate circuit. Thus the plate current is out of phase with the plate voltage and therefore the tube is equivalent to an impedance, in this case an inductance plus a resistance. The bias on the grid of the tube will vary the amount of inductance.

There are numerous variations of this circuit but they all work on the same principle. The difficulty is of course, to get exactly the right amount of control with the voltage developed by the discriminator. The circuit must be able to shift the oscillator frequency from 5 kc. to 15 kc. either direction according to the ideas of the designer. Moreover, it must shift the same number of kilocycles at any frequency setting throughout the tuning range of the receiver. This last requirement is much harder to fulfill. So far this particular problem has not been completely solved by the circuits shown here. One manufacturer has gone so far as to employ a double superheterodyne which has a fixed-frequency oscillator. Applying the correction to this oscillator will result in the same amount of correction throughout the range of the receiver.

A popular variation of the above corrector circuit is shown in Figure 9. Here the voltage applied to the grid is the drop across a condenser which is in series with a high resistance, R. Therefore this voltage is out of phase with the voltage across the combination R and C and will result in a plate current out of phase with this applied voltage. There are several other schemes, some of them employing two tubes.

APPLICATIONS

Several of the new 1937 receivers are supplied with a.f.c. systems although the popular name varies. They have also been incorporated in sets with automatic tuning systems where the listener can dial his station.

The system appears to work well on the broadcast band. It is subject to several peculiarities. Besides depending on the frequency of the incoming signal the control voltage also depends on its strength. So, if the incoming signal is weak and it fades, the circuit "drops" the station and it may not return when it fades back in because the dial adjustment may be too far off. The result will then be the usual inter station background noise. Some form of noise suppression system is desirable.

Variations in the characteristic of the control tube may cause trouble too. These tubes are generally run far below their rating so as to minimize the effect.

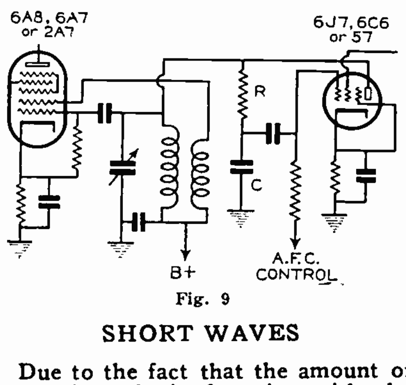

Fig. 9

SHORT WAVES

Due to the fact that the amount of correction obtained varies with the frequency, the correction possible on short waves becomes very large. It is for instance possible to shift the oscillator frequency 100 kc. or more with the result that the strongest station on a short wave band becomes audible all over the band while it becomes impossible to get weak stations. Furthermore, due to frequent fading of short-wave stations, the received signal may be dropped whereupon the circuit promptly takes hold of the next strongest carrier. On the other hand, slight variations of the oscillator frequency which are one cause of fading are compensated for.

Whenever the amount of correction can be kept fixed, as in the double superheterodyne the system should be very valuable on the higher frequencies.

ALIGNING

The serviceman who is called upon to align one of the a.f.c.-controlled receivers will have to follow a new technique. One of the recommended methods is as follows: First align the entire receiver with the a.f.c. cut out. Then couple the signal generator loosely to the grid of the last i.f. stage, the one which drives the discriminator. This may be done by bringing the output lead close to the grid cap. Have the signal generator unmodulated and tuned to the intermediate frequency. Tune in a station and adjust for zero beat between the station's carrier and the signal generator. Then switch in the a.f.c. circuit and retune the secondary of the discriminator transformer for zero beat. Zero beat should be obtained at both positions of the a.f.c. cutout switch. It may be necessary to go over the entire receiver again, repeating the entire performance as a final check.

THORDARSON OSCILLOSCOPE CONDENSER KIT

Once again Thordarson engineers have developed an essential piece of equipment in inexpensive kit form. This time it's the Thordarson Oscilloscope, utilizing the new 913 cathode-ray tube. This compact oscilloscope is just the thing for the enterprising serviceman or radio ham who wants to *see* what is really going on.

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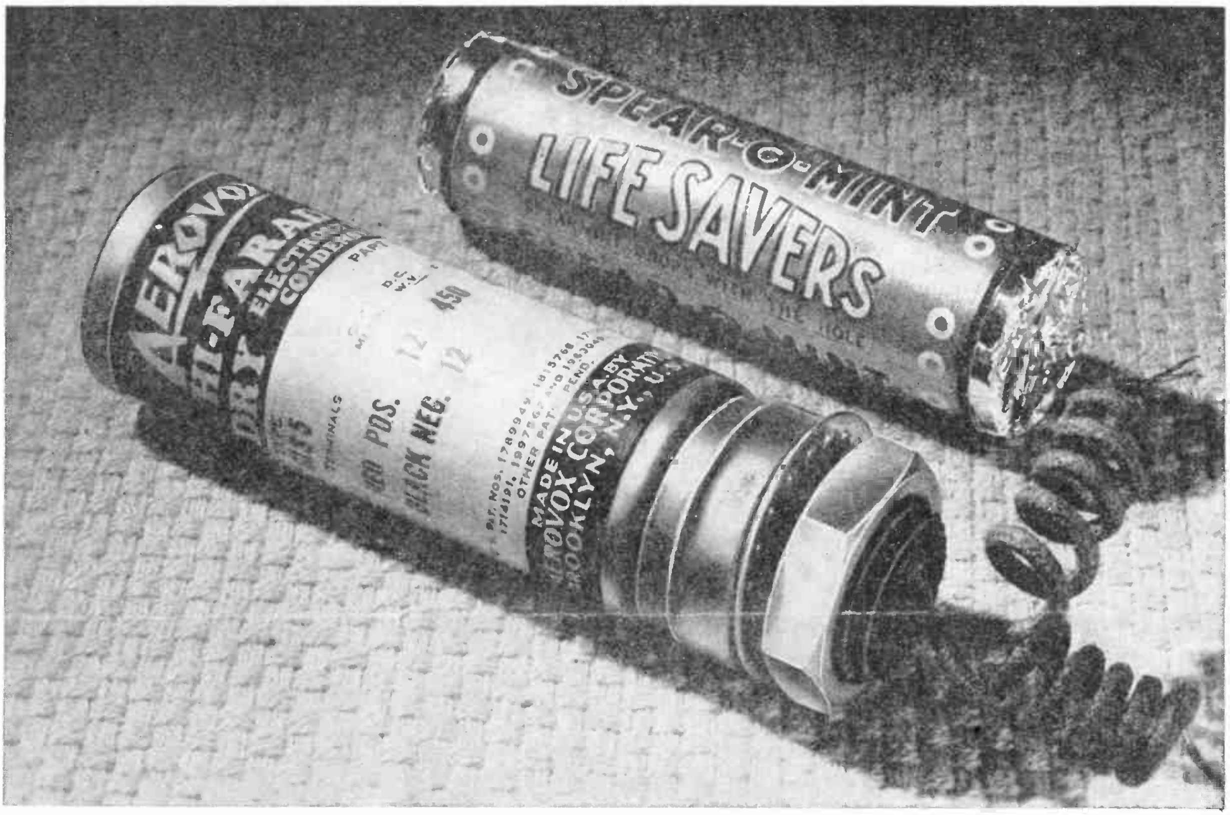

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