Feb. 13, 1945. C. TRAVIS 2,369,621

FREQUENCY MODULATION RECEIVER

Filed July 2, 1942

Fig. 1.

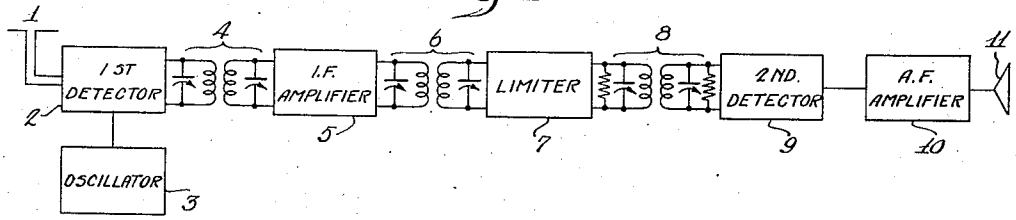


Fig. 2.

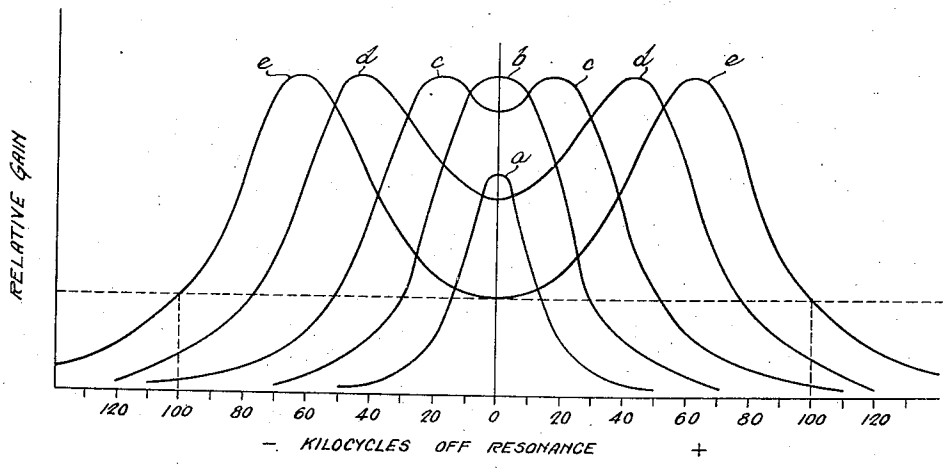


Fig. 3.

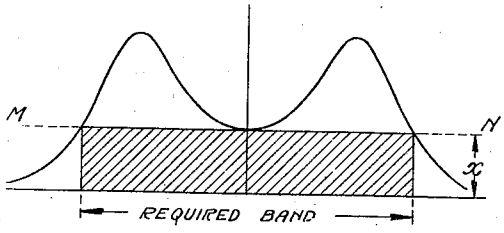
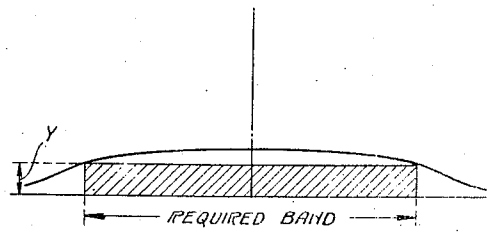


Fig. 4.



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UNITED STATES PATENT OFFICE

2,369,621

FREQUENCY MODULATION RECEIVER

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Application July 2, 1942, Serial No. 449,506

3 Claims. (Cl. 250—20)

This invention relates to frequency modulation receivers, and more particularly to an improved intermediate frequency transformer, and to the combination of an improved intermediate frequency transformer and an amplitude limiter.

In frequency modulation receivers equipped with amplitude limiters, irregularities in amplification and in frequency response characteristics are removed by the limiter, and hence, are of little importance in the detected result. By the present invention, advantage is taken of this fact in the adjustment of one or more of the intermediate frequency coupling transformers to provide increased selectivity and the maximum possible gain.

It is a principal object of this invention to provide an intermediate frequency amplifier-and-limiter combination adapted for use in frequency modulation receivers, having maximum gain and improved selectivity characteristics.

It is a further object of the invention to provide an intermediate frequency transformer unit having high gain, but low manufacturing cost, and adapted for use in frequency modulation radio receivers.

The invention itself, as well as other objects thereof, will be understood from the following description and the accompanying drawing, in which:

Fig. 1 is a schematic, and partially diagrammatic illustration of a frequency modulation receiver of the superheterodyne type embodying the present invention;

Fig. 2 is an explanatory diagram illustrating various frequency response characteristics obtainable by varying the coupling of an intermediate frequency transformer;

Fig. 3 illustrates the preferred frequency response characteristic of a transformer constructed in accordance with the invention; and

Fig. 4 illustrates the response characteristic of a typical intermediate frequency transformer constructed in accordance with the prior art.

Reference is now made to Fig. 1 in which there is illustrated a frequency modulation radio receiver of the superheterodyne type embodying the present invention. This receiver may comprise a suitable antenna 1, a converter stage comprising the first detector 2 and the local oscillator 3, an intermediate frequency coupling transformer 4, an intermediate frequency amplifier 5, a second intermediate frequency coupling transformer 6, an amplitude limiter stage 7, a third intermediate frequency coupling transformer 8, a second detector stage 9, an audio frequency amplifier 10, and a suitable sound output device 11. The present invention relates to a novel design and construction of the intermediate frequency transformers 4 and 6, and to the combination of said transformers with the amplitude limiter stage 7.

The family of curves of Fig. 2 illustrates the well-known variation of frequency response with coupling for the case of undamped, double-tuned, band-pass circuits of the type shown in Fig. 1 at 4 and 6. With loose coupling, i. e., below critical coupling, the frequency response characteristic of curve *a* is typical. This curve is characterized by having a single, relatively sharp, peak at the resonance frequency. The pass-band of such an under-coupled transformer is very narrow, and at 20 kilocycles off resonance the gain of this particular transformer is only a small fraction of its gain at resonance. The curve *b* illustrates the transformer's frequency response characteristic for the condition of critical coupling, i. e., where the coefficient of coupling is equal to the reciprocal of the square root of the product of the Q's of the coupled circuits. Curve *c* shows the frequency response characteristic for a slightly over-coupled condition, and is characterized by two response peaks, one on either side of resonance, with a valley or hollow between the peaks at resonance. By a further increase of the coefficient of coupling, the frequency response characteristic of curve *d* is secured, and with a still further increase in coupling the response characteristic illustrated by the curve *e* may be obtained, etc. The curves denoted *d* and *e* represent the condition of strong over-coupling.

According to one of the features of the invention the coupling between the windings of the intermediate frequency transformer is tightened to such an extent that the transformer gain at the edges of the useful band is substantially equal to the transformer gain at resonance. Assume, by way of example, that an intermediate frequency coupling transformer is to be designed for use in a frequency modulation receiver, and that a total intermediate frequency band-width of 200 kilocycles is required. By reference to the response curves of Fig. 2, taken for different values of coupling, it is evident that an equality of transformer gain at resonance and at 100 kilocycles off resonance is provided by the curve *e*, and this represents the preferred characteristic in accordance with the present invention. It should be understood, however, that the invention is not limited to this precise equality, it being sufficient that this relationship be only ap-

proximately met. For a 150 kilocycle band-width (one extending 75 kilocycles on either side of resonance) a curve lying intermediate curves *e* and *d* would preferably be selected.

In Figs. 3 and 4, there is afforded a comparison of the relative gain and selectivity characteristics of the improved transformer of the present invention and of a typical transformer of the prior art, respectively. In the gain characteristic illustrated in Fig. 3, the coupling between the transformer windings has been adjusted to the point where the gain at resonance is equal to the gain at the edges of the required frequency band. The band is denoted by the cross-hatched area below the curve, and the maximum useful gain is designated *x*. The response characteristic of Fig. 4 is usually obtained through the agency of a transformer having damped and slightly over-coupled windings, similar to the one illustrated at **8** in Fig. 1. This transformer, with its damping resistors removed, may have a characteristic similar to that designated *c* in Fig. 2. By the application of the damping resistors, however, the gain is reduced at all frequencies, but largely in the vicinity of the two peaks and at resonance, resulting in the substantially flat-top band-pass characteristic of Fig. 4. Here again the useful stage gain is that provided at the outer edges of the required frequency band, illustrated by the cross-hatched area underneath the curve. In practice, the response of the transformer is further flattened by the provision of an amplitude limiter following the transformer, thus giving a substantially uniform gain over the required band. In Fig. 4 this gain is denoted *y*. From a consideration of the response characteristics of Figs. 3 and 4 in the light of the general principles illustrated in Fig. 2, it is evident that gain *x* will always be greater than gain *y*, and, in fact, that the gain *x* is the greatest value of gain that may be reached as the coupling between the coils is increased.

It is also evident from an examination of the curves of Figs. 2, 3 and 4 that the selectivity of a transformer constructed in accordance with the present invention will be greater than that of a transformer constructed in accordance with the prior art. This is most clearly evident from Fig. 2, where it is apparent that the curve *e* has a steeper slope in the vicinity of 100 kilocycles off resonance than do any of the other curves.

It is apparent, of course, that the gain of a transformer of the character described varies greatly over the required band, with the result that a frequency-modulated signal, upon passage through the transformer, will emerge as a frequency-modulated signal with pronounced amplitude modulation. However, by providing an amplitude limiter to follow the over-coupled transformer, and adjusted to limit approximately along the line M—N of Fig. 3, this undesired amplitude modulation is eliminated along with other amplitude modulation components which it is the limiter's function to remove.

In the construction of the transformer of the present invention, it is desirable, in order to secure a maximum gain, to employ windings having a relatively high Q, and to avoid external forms of damping. The elimination of external damping resistors or other damping means, results, of course, in a simpler transformer of decreased manufacturing cost. The Q of the primary coils may conveniently be made equal to the Q of the secondary coils, but this procedure is not necessarily followed. The relative effects of changes in coil Q's and in the coefficient of couplings between the coils is too well known to require detailed comment. For the general laws relating to the various constants of coupled circuits of this character, reference may be had to Terman, "Radio Engineering," second edition, 1937, pages 88 to 92.

In considering the application of the present invention to a radio receiver of the superheterodyne type, reference may be had to Fig. 1 which has already been described in general terms. Transformers **4** and **6**, constructed in accordance with the principles of the present invention, may be employed as the coupling means between the first detector stage **2** and the intermediate frequency amplifier **5**, and between the said amplifier stage and the limiter stage **7**. If additional intermediate frequency amplifier stages are provided, similar transformers may advantageously be employed in the couplings between the several stages. If transformer coupling is employed between the limiter stage and the second detector stage, and no additional amplitude limiting means are associated with the said transformer, it is preferred to employ, at this point, a transformer of the conventional type, having a band-pass characteristic of the character illustrated in Fig. 4. In order to secure this characteristic, the windings of the transformer may conveniently be damped by the addition of suitable resistors connected in shunt with the primary and secondary windings thereof, as indicated at **8** in Fig. 1.

In conventional intermediate frequency amplifier practice, it is known to detune certain of the individual stages by small amounts to secure a desired overall frequency and phase characteristic. This is known as "staggering," and this procedure may be utilized in the practice of the present invention without departing from the spirit thereof.

Although the invention has been described with particular reference to a specific embodiment, it will be understood that the invention is capable of general application and is adapted to other forms of physical expression and is, therefore, not to be limited by this specific disclosure, but only by the scope of the appended claims.

What is claimed is:

1. In a frequency modulation receiver of the superheterodyne type, an intermediate frequency transformer comprising tightly-coupled primary and secondary windings, means for tuning said windings to produce an overall transformer responsive characteristic having a pronounced resonant peak on each side of the receiver's intermediate frequency and substantially equidistant therefrom, the coupling between said tuned windings being such that the transformer gain at the point of minimum gain between peaks is substantially equal to the transformer gain on the outer slopes of said peaks at the edges of the receiver's intermediate frequency band, an amplitude limiter following said transformer and operative to limit the signal amplitude to a level substantially corresponding to said point of minimum gain, a detector circuit following said amplitude limiter, and a coupling device having a substantially flat-top band-pass characteristic connected between said limiter and said detector.

2. In a frequency modulation receiver of the superheterodyne type, an intermediate frequency amplifier whose frequency response characteristic has a pronounced resonant peak on each side of the receiver's intermediate frequency and sub-

stantially equidistant therefrom, the amplifier gain at the point of minimum gain between peaks being substantially equal to the amplifier gain on the outer slopes of said peaks at the edges of the receiver's intermediate frequency band, an amplitude limiter following said amplifier and operative to limit the signal amplitude to a level substantially corresponding to said point of minimum gain, a detector circuit following said amplitude limiter, and a coupling device having a substantially flat-top band-pass characteristic connected between said limiter and said detector.

3. In a frequency modulation receiver of the superheterodyne type, an intermediate frequency amplifier including a plurality of intermediate frequency transformers, the overall frequency response characteristic of said amplifier having a pronounced resonant peak on each side of the receiver's intermediate frequency and substantially equidistant therefrom, the amplifier gain at the point of minimum gain between peaks being substantially equal to the amplifier gain on the outer slopes of said peaks at the edges of the receiver's intermediate frequency band, and an amplitude limiter following said amplifier and operative to limit the signal amplitude to a level substantially corresponding to said point of minimum gain.

YVONNE TRAVIS.
Administratrix of the Estate of Charles Travis, Deceased.