

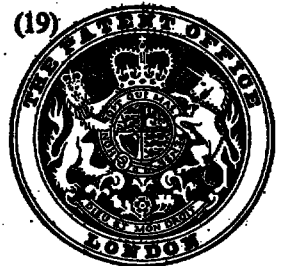
PATENT SPECIFICATION

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(54) IF AMPLIFIER

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady 12305, State of New York, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to an IF amplifier for an AM-FM receiver. The AM-FM receiver has a d.c. coupled IF broad-band IF amplifier comprising a plurality of stages of emitter coupled transistor pairs. A d.c. feedback network is provided to balance the individual stages and to generate a control potential for further use in mode conversion. In the FM mode, the IF amplifier operates with a high, stable gain at the FM IF frequency with gain reduction for noise suppression purposes below the FM IF frequency. Frequency dependent noise suppression is provided by a capacitance associated with the degenerative network. In the AM mode, the IF amplifier operates at a controllable, medium gain with the degenerative effect on IF gain restored at the AM IF frequency by the addition of capacity to the degenerative network. A control bus, energized by the degenerative network, is used for gain control purposes in the AM tuner and for mode conversion in the AM tuner, the AM-FM detector, and separate portions of the AM and FM audio circuitry.

A radio receiver utilizing some of the same circuit elements and a selected organization of the mode conversion measures is described in copending application No. 35886/77, (Specification No. 1,503,172).

An AM-FM detector similar to that herein described is the subject of copending applicant No. 13415/75, (Specification No. 1,511,041).

The invention deals with means for converting the radio receiver from AM to FM and optionally to phono operation while at the same time optimizing the individual circuits for each mode of operation. Optimization is achieved in noise filtering, particularly in the FM mode, automatic gain control in AM, automatic frequency control in FM and temperature compensation in FM.

Radio receivers for AM and FM operation have been proposed fabricated primarily of integrated circuitry. In integrated circuit fabrication, increased circuit complexity produces little increase in costs, thereby permitting highly sophisticated circuitry even in low cost applications. Because of the cost advantage in integration, it is desirable to integrate a maximum amount of the circuitry with a minimum of non-integrated or "out-boarded" components. Cost considerations also dictate a minimum pin count. In carrying out radio receiver functions, optimization of each function for either the AM or FM mode is desirable and the conversion between modes should be readily achieved. For instance, it is essential to provide an IF amplifier which is of a high and stable gain for FM operation, while for AM operation less gain is required and the gain should be readily controlled. Similarly, the detection function should be separately optimized for the AM and for the FM detection modes and for easy conversion between these two modes. A suitable IF amplifier is a d.c. coupled broad band amplifier incorporating a plurality of emitter coupled transistor stages and utilizing degenerative feedback for balance. Such an amplifier is disclosed in the first cited copending application. A suitable AM-FM detector is described in the second cited copending application. A known technique for enabling and disabling functional circuits of this nature is through the use of controlled transistor current sources which are in turn responsive to the

setting of a manual switch.

The present invention is an intermediate frequency (IF) amplifier for a radio receiver capable of receiving in the AM mode or FM mode, the IF amplifier being d.c. coupled and arranged to amplify signals at frequencies both in a frequency range centred on a higher FM IF, and centred on a lower AM IF, the amplifier comprising:

- 10 (a) a plurality of consecutive stages, said consecutive stages considered collectively, having wide band a.c. gain embracing both said ranges, each such consecutive stage including an emitter coupled transistor pair
- 15 comprising an input transistor and an output transistor, there being provided for each such pair an emitter-resistor arranged to pass the emitter currents of both transistors of its respective pair, those ends of said emitter-resistors which are remote from the respective emitters being connected together and to an earth-line or earth-point,
- 20 (b) a primary bus through which is to be applied d.c. collector operating current to the individual transistors of said consecutive stages,
- 25 (c) a secondary bus for passing d.c. base current to the output transistor of each said pair and for applying degenerative feedback to provide balanced biasing of each said transistor pair,
- 30 (d) means for establishing said secondary bus at a potential which is a function of the potential of said primary bus and for applying said degenerative feedback to said secondary bus, including
- 35 (1) a collector load resistance connected between said primary bus and the collector of the output transistor of the last of said consecutive stages, and
- 40 (2) a degenerative feedback resistance having one end connected to the collector of the output transistor of the last of said consecutive stages and the other end connected to the base of said output transistor of the last of said consecutive stages and to said secondary bus,
- 45 wherein the said collector load resistance and feedback resistance, and the circuits associated with said consecutive stages are so designed or selected, that
- 50 (A) when there is applied *via* said primary bus the aforesaid d.c. collector operating current in the FM mode at a first value lying in a first range of current values, the primary bus is at a first d.c. potential, lying in a first range of potential values, with respect to earth and the IF amplifier exhibits a first value of overall IF amplifier a.c. gain, and
- 55 (B) when there is applied *via* said primary bus the aforesaid d.c. collector operating current in the AM mode at a second and different value lying in a second range of current values, the primary bus is at a second and different d.c. potential, lying in a second
- 60
- 65

range of potential values, with respect to earth, and the IF amplifier exhibits a second and different value of overall IF amplifier a.c. gain lying in a range of gain values,

(C) the second value of gain being variable in accordance with the d.c. potential on said secondary bus, as derived from said potential of second value on said primary bus and as transmitted *via* said secondary bus to said output transistors, and

75 wherein each said transistor pair comprises a conductor-connection from the primary bus to the collector of the input transistor of the pair, a collector load resistor connected between the primary bus and the collector of the output transistor of the pair, a conductor-connection which interconnects the emitter of the transistors of the pair and also the non-earthed end of the respective said emitter-resistor, and a conductor-connection from the collector of the output transistor of the pair to the base of the input transistor of the next higher stage, and the basis of said output transistors are conductor-connected to said secondary bus, 80 and further wherein for the resistance pairs there is a uniform ratio of resistance value of the collector load resistor of the output transistor of any pair to the resistive value of the commoned emitter load resistor of such given pair, such uniform ratio being substantially one to one.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram of an AM-FM receiver embodying the invention;

Figs. 2A and 2B, hereinafter collectively considered as Fig. 2, are an essentially complete circuit diagram of the embodiment of Fig. 1, omitting primarily the audio power amplifier;

Fig. 3 is a diagram of a modified switch for mode conversion of the receiver between AM, FM and phono modes of operation; and

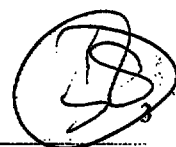
Fig. 4 is a graph of the frequency response of the intermediate frequency amplifier attributable to the degenerative feedback network and producing improved noise performance.

DESCRIPTION OF A PREFERRED EMBODIMENT:

A radio receiver embodying the invention is shown in simplified block diagram form in Figure 1. The radio receiver takes the general form of a super-heterodyne receiver and is intended for AM, FM and phono operation. Of particular interest and those features directed to low radio frequency noise filtering, conversion of the receiver between the three individual modes of operation, and improved AGC action.

The radio receiver of the embodiment is

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designed for integrated circuit fabrication. In both Figures 1 and 2, the line of separation between the outboarded components and those on the integrated circuit are established by the "pads" to which external electrical connections are made.

Signal conversion to a pair of fixed intermediate frequencies is achieved in the blocks 21 to 30 comprising the "front end" or tuner of the receiver. The FM portion of the tuner is not on the integrated circuit. It includes an FM transistor mixer 21 shown with an input connection to a source of FM signals, typically a whip antenna. An FM transistor local oscillator 22 is provided whose output is coupled to the FM mixer to produce signals at a first higher intermediate frequency, typically 10.7 megahertz. The FM IF signal is filtered in the FM IF filter 27 before application through pad 2 to the IF amplifier (34, 35) on the integrated circuit. For mode conversion, and in particular for enabling and disabling the FM portion of the front end, a selector switch 29 is provided whose movable contactor is coupled to the input junction of the transistor of the FM oscillator 22. In the AM position, the movable contactor contacts a first stationary contact, which is grounded and which disables the FM oscillator. In the FM position, the contactor couples the oscillator input junction to a second stationary contact connected to a source of positive d.c. potentials (+1.2 volts) selected to forward bias the input junction of the FM oscillator transistor. In the phono position, the movable contactor is isolated from either stationary contact, which as will be explained, also leaves the FM portion of the tuner in a quiescent state.

For AFC action, the FM mixer is coupled through pad 16 to a bus 31 on the integrated circuit denominated the primary control bus. As will be described, the voltage on bus 31 varies with the output of the AM-FM detector. In the FM mode, this output is applied to the FM local oscillator to adjust its frequency in a sense to reduce drift.

The AM portion of the tuner includes an AM antenna tuned circuit 25 having a ferrite element for remote reception of AM signals, an AM mixer 23 includes integrated active transistor circuitry, an AM local oscillator tuned circuit 26, an AM oscillator 24, including integrated active transistor circuitry, an AM IF filter 28 and a second selector switch 30 ganged with switch 29 for mode conversion. The output of the AM oscillator 24 is coupled on the integrated circuit to the AM mixer, and the heterodyned output at the lower intermediate frequency of 455 kilohertz appears at the mixer output (pad 4) where it is filtered by the AM IF filter 28 prior to re-introduction at pad 2 to the integrated circuit through the series

connected FM IF filter 27.

Mode conversion of the tuner for the AM portion is controlled by the second switch 30. The second switch has a movable contactor operable into contact with a first stationary contact, which is grounded, and used when the radio receiver is in the FM mode of operation. The movable contactor may also contact a second stationary contact for the AM mode of operation. The second stationary contact is returned to pad 1 on the chip. Pad 1 is coupled to a bus 32 on the integrated circuit denominated the secondary control bus, which has a small varying positive d.c. potential (0.8 to 1.2 volts) for the AM mode. As will be described, the voltage on bus 32 varies with detector output to perform an automatic gain control function. The movable contactor of switch 30 is connected to pad 7 which is in turn coupled to the third or mode switching control bus 33. The AM mixer 23 and AM oscillator 24 are returned to bus 33 for mode switching and AGC action. When the switch 30 is in the FM position (with the third control bus grounded), the input junctions of the transistors controlling AM mixer and AM oscillator currents are biased off, precluding operation. In the AM position, the small, signal dependent, positive potentials on the third control bus turn on the input junctions controlling the mixer and AM oscillator and provide automatic gain control action of the AM portion of the tuner. (As will be developed, the control bus 33 is of general use for mode conversion of several other portions of the radio receiver).

The integrated IF amplifier 34, 35 is a broad band, d.c. coupled amplifier designed to amplify signals from the AM-FM tuner at either the 455 kilohertz or 10.7 megahertz IF frequency to a level suitable for detection. Essential selectivity for suppressing interchannel interference is provided by the AM and FM input (27, 28) and output (40) filters. The IF amplifier 34, 35 includes five d.c. coupled transistor stages having a potential a.c. gain of approximately 15 db per stage at optimum d.c. bias. The d.c. gain of the first four stages (34) is approximately unity because of the degenerative feedback network. Neglecting the input and output filters, and roll off attributable to capacitance in the degenerative feedback network, the IF amplifier amplifies from audio frequencies to an upper frequency limit in excess of 10.7 megahertz.

The IF amplifier 34, 35 is convertible between an AM and FM mode of operation and participates in effecting mode conversion of other portions of the radio receiver. Mode conversion of the IF amplifier is achieved in response to a change in the d.c. potential on the primary control bus 31. The d.c. potential on bus 31 is in turn controlled

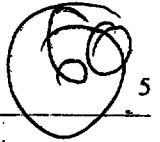
by a main current source 129, which comprises a current source 54 and a current amplifier 36, in response to the mode setting and signal level. The primary control bus 31 supplies collector bias to the transistors making up the first four stages (34) of the IF amplifier, while the fifth stage (33) is provided with separate collector bias. In the FM mode of operation, the collector bias on the bus 31 is established at a relatively high value, typically 2.5 volts. This voltage produces optimum signal gain and reduces the sensitivity of the IF gain to small variations in bus potential. With the usual FM signal, the IF gain is normally adequate to produce signal limiting. For AM operation, the collector bias on bus 31 is established at a much lower value, typically 1.5 volts. This lower voltage produces several db less gain per stage and makes the gain of the IF amplifier more sensitive to variations in potential on the primary control bus. In the AM mode setting, the gain control range of the IF amplifier is about 30 to 40 decibels.

The IF amplifier 34 participates in effecting mode conversion of other portions of the radio receiver by means of its energization of the secondary control bus 32. The secondary control bus is energized through the degenerative feedback network in the fourth stage of the IF amplifier. The complete circuit of the IF amplifier is shown in Figure 2, while in Figure 1, only those portions of the IF amplifier circuit which are necessary to explain the energization of the secondary control bus and the operation of the degenerative feedback network are shown. In particular, while each of the five stages of the IF amplifier (34, 35) are formed of emitter coupled transistor pairs, only circuitry of the fourth stage is illustrated in Figure 1. The fourth stage comprises a pair of differentially coupled transistors Q7, Q8, the first transistor of which is in an emitter-follower configuration and the second of which is in the emitter input-bias-common configuration. As may be seen in Figure 2A, for the first four stages there is a uniform ratio of resistance value of collector load of the output transistor of each given stage pair to the resistance value of the commoned emitter load resistor of the given stage pair, such uniform ratio being substantially unity. The IF input signal to the fourth stage is applied to the base of the first transistor (Q7) of the pair and the collector of the first transistor is connected to the primary control bus 31 for collector bias energization. The output appearing at the emitter of the first transistor Q7 is coupled to the emitter of the second transistor (Q8). The collector of transistor Q8 is the point at which the output signal of the fourth stage appears. The collector of Q8 is connected to the primary control

bus 31 through a collector load resistance 38 and through a degenerative feedback resistance 39 to the base of Q8. The base of the transistor Q8 is connected to the secondary control bus 32. The control bus 32 which is energized through resistances 38, 39 is coupled via pad 1 to a first filter capacitor 62. Capacitor 62 provides a first capacitance value between the control bus and ground, which is present in all mode settings and which produces a first frequency dependent modification of the degenerative feedback in the AM mode setting. The control bus 32 is coupled via the mode selection switch 30 to a second capacitor 63 connected to the third control bus 33. Capacitor 63 in parallel with capacitor 62 provides a second larger capacity acting between the secondary control bus and ground effective only in the AM mode setting. The paralleled capacitance of C62 and C63 produces a second frequency dependant modification of the degenerative feedback in the FM mode setting.

The d.c. voltage on the secondary control bus 32 is dependent on the mode setting and on the level of the detected signal since it is dependent on the voltage on the primary control bus. It is also dependent on the magnitudes of the resistances 38 and 39. Upon conversion from the FM to the AM mode, the potential on the primary control bus 31 is reduced (2.5 to 1.5 volts) producing a slightly less than proportional reduction in the potential on the secondary control bus (1.8 to 1.2 volts). The voltage on the secondary control bus at the same time varies in approximate proportion to the changes in the voltage on the primary control bus which arise from signal dependent changes. In the FM mode, the voltage on the primary control bus varies from 2 to 3 volts as a result of signal de-tuning. In the AM mode, the voltage on the primary control bus varies from about 1.5 to 0.85 volts as a result of changes in signal level.

The secondary control bus 32, which reflects the potentials on the primary control bus, is usable for further mode switching and for automatic gain control. In the initial four stages of the IF amplifier, the bases of the output transistors Q2, Q4, Q6, and Q8 are returned to the secondary control bus while the emitters are returned to ground. Thus, variations in the potential on the secondary control bus attributable to variations in detector output produce emitter current changes in each of these four differential stages of the IF amplifier. Changes in the emitter current change the transistor transconductance and produce the desired automatic gain control action. Since the source energizing the secondary control bus 32 is the relatively high impedance, low current fourth IF transistor stage,



the loading on the secondary control bus should be small. In the illustrated circuit, the load current required for control purposes is less than 20 microamperes.

- 5 The d.c. gain variations attributable to the degenerative feedback network is invariant with the setting of the mode selection switch 30, but the a.c. gain, which produces significant noise reduction, is dependent on the mode setting. Resistors 38 and 39 in the degenerative feedback network are typically of the same value (1K each) and are selected to reduce the d.c. gain of the fourth stage of the IF amplifier to near one. D.C. connections of the bases of prior transistors in the IF amplifier to the control bus 32 similarly reduce the d.c. gain of each of the first four stages to one. The total d.c. gain of the four stages is thus near one and substantially the same in either mode setting.

- 20 The a.c. gain reduction attributable to the degenerative network is dependent on the mode setting. In the FM mode setting, capacitor 62, in combination with other fixed circuit parameters of the IF amplifier 34, causes increasing degeneration below the FM IF frequency. The noise problem, which the degenerative network is designed to solve is encountered principally in FM reception. Here the interference tends to occur throughout the broadcast band spectrum from strong local signals and from signals converted to the AM IF frequency. Suppressing the low frequency response of the IF amplifier below 10 MHz reduces both sources of stray pick up and produces a general noise immunity. In AM reception, while the possibility of stray pick up is smaller, the circuit provides greater noise immunity.

- 30 The degenerative feedback network provides the RC "doublet" action shown in the FM and AM frequency response curves of Figure 4. The network produces a high pass condition above the higher frequency break, a band attenuation condition below the lower frequency break, and an intervening region having a 6 db per octave slope. In the FM setting, the lower frequency break is inversely proportional to the product of the feedback resistance 39 (1000 ohms) and the capacity of capacitor 62 (.02 microfarads). The higher frequency break is proportional to:

$$\frac{K_{FM}}{R39 (C62)} \quad (1)$$

- 60 where K_{FM} is the d.c. gain of the first four IF stages in the FM setting. The higher break is normally selected to be below the FM IF frequency, i.e., 3 to 10 megahertz, while the lower break is around 10 kilo-

hertz, in this embodiment 8 kilohertz.

In the AM mode, both capacitor 62 and capacitor 63 are paralleled. These two capacitances, in combination with other fixed circuit parameters lower the frequency of the upper break to below the AM IF frequency to restore the AM signal gain. The network introduces degeneration commencing at a point below the AM IF frequency. This causes further noise reduction.

The frequency of the higher break for AM operation is proportional to:

$$\frac{K_{AM}}{R39 (C62 + C63)} \quad (2) \quad 80$$

where K_{AM} is the d.c. gain of the first four stages in the AM setting. The higher break is conveniently between 50 and 200 KHz, placing the lower break at about three kilohertz, in this embodiment 2.6 kilohertz.

The last stage (35) of the IF amplifier is coupled through the AM-FM filter 40 to the AM-FM detector 41. Stage 35 consists of a fifth emitter coupled pair of transistors Q9, Q10. The circuit configuration is shown in Figure 2. The bases of transistors Q9 and Q10 are coupled respectively to the upper and lower terminals of the degenerative feedback resistance 39. The emitter current of Q9, Q10 is supplied by the current source Q12. The collector of Q9 is connected to the 6 volt B+ bus on the chip, while the collector of Q10 is d.c. coupled via pad 15 through the AM-FM filter 40 to the 6 volt B+ bus. By virtue of the connection of the emitters of Q9, Q10 to the current source Q12, the transistors Q9, Q10 are not subject to AGC action as the voltage on the secondary control bus varies the base potentials. Thus, the last stage Q9, Q10 operates in a high gain condition unreduced by any controls.

In the interest of maximizing the gain of the IF amplifier and of reducing imbalance current to a minimum, which tends to reduce gain, the areas of the transistor pair Q9, Q10 are unbalanced to take into account the differential in d.c. potentials applied to the bases of Q9 and Q10 as a result of current flowing in the feedback resistor 39. This voltage drop is typically a few tens of millivolts as compared to the diode drop of several hundred millivolts. Any imbalance in emitter current is readily corrected by making the area of transistor Q9, which has the higher forward bias, proportionally smaller than the area of the transistor Q10 to equalize the currents for zero signal conditions. (Degenerative feedback in the prior four stages of the IF amplifier maintains d.c. balance, thereby maximizing the stage gain in the prior stages.)

Signal detection and audio amplification 130

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following the IF amplifier 34, 35 and the AM-FM filter 40 take place in the AM-FM detector 41; the FM audio block 42; AM audio block 43; and the audio power amplifier 44. A phono input connection 45 and a volume control 46 for controlling the AM-FM and phono inputs is also provided.

The detector and audio elements are interconnected in a conventional fashion. The output of the IF amplifier 34, 35 is coupled through the AM-FM filter 40 to the AM-FM detector 41. The AM-FM detector is provided with two output connections, one to the FM audio (42) and the other to the AM audio (43) block. When the AM-FM detector is in the FM mode, its output signal contains pulse width modulations reproducing the original frequency modulation. This signal is coupled to the FM audio block 42, which converts the variable width pulses into a conventional amplitude modulated waveform suitable for amplification in the audio power amplifier 44. When the AM-FM detector is in the AM mode of operation, it operates as a peak detector of the amplitude modulated signal. The AM audio block 43 preamplifies the detected output to a level suitable for driving the audio power amplifier 44.

The detected AM and FM signals and the phono inputs are combined at the volume control 46 for application to the audio power amplifier 44. The audio signal output of the FM audio block 42 and AM audio block 43 are coupled to the pad 8 and through the capacitor 47 to the first end terminal of the volume control 46. A noise filtering capacitor 48 by-passes pad 8 to ground. The phono input jack 45 is coupled through an impedance matching resistance 50 (whose magnitude depends on the impedance and output level of the phono cartridge) to the same first end terminal of the volume control 46. The other end terminal of the volume control is grounded. The tap on the volume control is coupled through a 22K resistance 49 to the pad 9 leading to the input of the audio power amplifier 44. A capacitor 51 for high frequency roll off is coupled between pad 9 and ground. The configuration permits one to optionally drive the audio power amplifier 44 from either the output of the FM audio block, or the output of the AM audio block, or the phono input. The audio output of the power amplifier drives the loudspeaker 52.

The remaining blocks in Figure 1 pertain to the power supplies and to the application of power to the signal circuits for mode selection. The remaining blocks include the current amplifier 36 mentioned earlier, its associated controlled current source 54, the switched current sources 55, 56 and 57 associated respectively with the AM-FM detector 41, the FM audio 42 and the AM

audio 43, and the 1.2 volt temperature compensated source 53.

Taking up the power supplies, the primary source of energy for all of the radio receiver circuitry is the external 6 volt source 58 coupled to the double pads 13. This source may take the form of a battery or rectifier and filter operating from a 110 volt a.c. main. The lower segment of the pad 13 is used to provide power for the audio power amplifier 44, while the upper segment is used to energize the temperature compensated 1.2 volt source 53 and other portions of the radio receiver. A second uncompensated 1.2 volt source is developed within the audio power amplifier. The latter 1.2 volt source is used to provide a start up control for the temperature compensated source 53 and for mode conversion of the FM tuner. The latter 1.2 volt source is coupled to the pad 10, by-passed to ground by a large filter capacitor and coupled to the stationary FM terminal of the mode selection switch 29.

Mode selection of the radio receiver (FM tuner excepted) is controlled by the mode selection switch 30 acting upon the current sources 54, 55, 56 and 57. The mode switching control bus 33, whose voltage is at zero in the FM setting of the mode selection switch 30 and at a small positive potential (0.8 to 1.2 volts) in the AM setting is coupled to the AM mixer, the AM oscillator (both earlier noted), the controlled current source 54 and all three switched current sources 55, 56 and 57. The output of the 1.2 volt temperature compensated source is coupled via a fourth bus 60 to the AM mixer, the controlled current source 54 and two switched current sources 55 and 56.

Mode selection of the AM mixer 23 and AM oscillator 24 is achieved by the circuitry shown in Figure 2. The AM mixer consists of a four quadrant multiplier consisting of two pairs of differentially connected transistors (Q13, Q14, Q15, Q16) in an upper rank and a single pair of differentially connected transistors Q30, Q31 in a lower rank. The AM signal is applied to the bases of the lower rank transistors and the oscillator signal is applied to the bases of the upper rank transistors Q14, Q15. The lower rank transistors act as a current source for establishing the amount of current available to the transistors in the upper rank. The direct current level in the lower rank transistors Q30, Q31 is in turn governed by the bias on their input junctions. The emitters of Q30, Q31 are returned to ground through a tapped resistance R16, R18, while the bases of Q30, Q31 are returned to the third control bus 33, which establishes bias on their input junctions. When the control bus 33 is provided with a small positive potential as occurs in the AM setting of the



selector switch 30, the input junctions of the lower rank transistors Q30, Q31 are biased on, making current available to the AM mixer and enabling the circuit to operate. In the FM setting of switch 30 the bases of the lower rank transistors Q30, Q31 are returned to ground. In this setting the lower rank transistor junctions have inadequate forward bias, turning off the current in the AM mixer and forcing the circuit into quiescence.

Mode selection of the AM oscillator is best understood by reference to Figure 2. The AM oscillator is comprised of a differentially connected pair of transistors Q32, Q34, whose emitter current is supplied by an additional transistor current source Q33. The emitter of the transistor current source Q33 is returned to ground through a low resistance and its base is connected to the third control bus 33. When the mode switch 30 is in the AM position, current source transistor Q33 is turned on, supplying current to the AM oscillator and permitting oscillation. In the FM setting of the switch 30, the base of the current source Q33 is grounded, removing the forward bias and turning off. When Q33 is turned off, operation of the AM oscillator is precluded.

The mode selection of the IF amplifier is also dependent on the mode setting of switch 30, which affects the potential on the primary control bus 31. As earlier noted, when the potential on the primary control bus 31 is low for AM operation, the IF gain is lower and controllable in response to signal dependent voltage changes on the bus. When the potential on bus 31 is high for FM operation, the IF gain is high and signal dependent voltage changes on the bus are used for automatic frequency control of the FM tuner. The potential on bus 31 is controlled by the current amplifier 36, which is controlled by current source 54.

The controlled current source 54 is further divided into two individual current sources, one (Q22, Figure 2) of which is controlled in response to the average level of the audio signal appearing at the pad 8 and resulting from outputs of either the FM audio or AM audio blocks. The second individual current source (Q23, Figure 2) of 54 is controlled by the voltage difference existing between the 1.2 volt temperature compensated bus 60 and the mode switching control bus 33. In the AM setting of switch 30, which elevates the potential on bus 33 to slightly under the potential on bus 60, the Q23 current source is turned off as a result of a reduction in forward bias of the input junction. When Q23 is turned off, the current supplied to the current amplifier 36 is reduced and the voltage at the primary control bus 31 is reduced to about 1.5 volts required for gain controlled AM operation. In the FM

mode setting of switch 30 the bus 33 is grounded, the forward bias on the input junction of Q23 is increased turning it on and increasing the current supplied to current amplifier 36. This elevates the voltage on the primary control bus 31 to 2.5 volts required for high gain FM operation of the IF amplifier.

The mode setting of the AM-FM detector 41 is also controlled by the switch 30, which controls the current supplied thereto. The AM-FM detector is designed to function in an FM detection mode in a high current condition when FM signals are supplied in reference phase and in quadrature phase. The output takes the form of a pulse width modulation reproducing the modulating signal. In the FM setting of the switch 30, the bus 33 is grounded, forward bias is provided to the input junction of Q25, turning it on strongly, and increasing the current available to the detector as required for proper FM detection. In the AM setting, the AM-FM detector is designed to function as a peak detector in a very low current condition. The amount of current available to the AM-FM detector is established by the switched current source 55 (transistor Q25, Figure 2), which is controlled by the voltage difference existing between the 1.2 volt temperature compensated bus 60 and the mode switching control bus 33. In the AM setting of the switch 30, which elevates the potential on bus 33 to slightly under the potential on bus 60, current source 55 is turned off. The only current available to the detector 41 is then a few microamperes of base current available from the following audio preamplifier 43. This permits operation of the AM-FM detector as an AM peak detector.

The mode setting of the FM audio block 42 is controlled in the same manner as the AM-FM detector by the switch 30. The FM audio block is provided with current from the switched current source 56 (transistor Q26, in Figure 2). That current source is controlled by the voltage difference existing between the 1.2 volt temperature compensated bus 60 and the mode switching control bus 33. In the AM setting of switch 30, which elevates the potential on bus 33 to slightly under the potential on bus 60, the switched current source 26 is turned off, disabling the FM audio block. In the FM setting of the switch 30, the bus 60 is grounded, the forward bias on the input junction of Q26 is increased, turning it on and supplying the current requisite for operation of the FM audio block.

The mode setting of the AM audio block 43 is controlled in a complementary manner to that of the FM audio block. The AM audio block is provided with current from the switched current source 57 (transistor Q29, Figure 2). The emitter of the (NPN)

transistor Q29 is returned to ground while its base is coupled to the third control bus. In the FM mode setting, with the third control bus grounded, the transistor Q29 is turned off, preventing any supply of current to the AM audio block and disabling it. In the AM mode setting of the control switch 30, the base of Q29 is provided with a substantial forward bias, turning it on and in turn turning on the AM audio block 43.

The AM-FM mode conversion may be summarized. In the FM mode, the FM tuner (including mixer 21 and oscillator 22) is turned on or off by the selector switch 29. The condition of the other blocks is dependent on selector switch 30. The IF amplifier 34, 35 is switched to a high collector bias-high gain condition by setting selector switch 30 to the FM position. Switch 30 increases the current in the current source 54 which supplies more current to current amplifier 36. The AM-FM detector is set to a high current state by setting switch 30 to the FM position, which turns on current source 55. Finally, the AM audio block 43 is turned off by setting switch 30 to the FM position which turns off current source 56. In the AM mode, the FM tuner is turned off by the selector switch 29. The condition of the other blocks is again dependent on selector switch 30. In the AM position of selector switch 30, the AM mixer and AM oscillator 23, 24 are turned on, the current amplifier 36 is turned to a low current setting by the controlled current source 54; the AM-FM detector 41, the FM audio block both have their respective current sources (55, 56) switched off; and the AM audio block 43 is turned on by its current source 57.

The foregoing AM-FM mode conversion is also consistent with a third, phono mode in which neither the AM nor FM portions of the radio receiver are in operation. A phono input is provided at the volume control 46 which controls the AM and FM outputs. Thus, all three sources may be coupled to the input of the audio power amplifier 44 where they may be used to drive the loudspeaker 52. The phono mode may be added without further alteration other than the addition of an intermediate position to the selector switches 29 and 30. The intermediate position should allow movable contactors to be isolated from both the AM and FM stationary contacts. This configuration is economically most advantageous, since it permits the switches to be of a minimum cost. In the phono setting, the FM tuner is inoperative since there is no adequate bias, the AM mixer and AM oscillator are inoperative; the current sources 54, 55, 56 and 57 are all in a low current condition precluding operation of the AM-FM detector 41, the FM audio 42, the AM audio 43. Finally, since the current amplifier 36 is jointly res-

ponsive to the detected signal level (Q22) and switched current source (Q23), both controls reduce its current output and disable the IF amplifier. Thus, in this intermediate switch position neither the AM nor FM portions of the receiver contribute to the audio output. In the event that additional costs may be tolerated, the mode switches may each have an added stationary contact for the phono setting. In that form, the stationary phono contactor for switch 29 should be grounded, while the stationary phono contactor for switch 30 should be grounded through a resistance (Figure 3).

The major circuitry of a radio receiver embodying the present invention is depicted in Figure 2. While reference has been made to several portions of that circuitry in the prior discussion, several other circuit portions are of interest in facilitating an understanding of the invention and the precise manner in which the block diagram of Figure 1 is implemented.

The circuit of the FM tuner is optimized for easy mode switching and is readily subjected to automatic frequency control. The FM tuner consists of a serially energized mixer 21 and oscillator 22, both deriving current from the same point of connection to the primary control bus. The mixer 21 includes a tuned antenna circuit (shown generally at 74) coupled to the base of the mixer transistor TR1. The collector of TR1 is d.c. coupled to the primary control bus 31 through the inductor of the IF filter 27 and a 100 ohm resistance 71. The FM oscillator 22 includes a second tuned circuit 72 and a second transistor TR2. The emitter of the transistor TR1 is coupled through the d.c. path provided by the inductor of tuned circuit 72 to the collector of the oscillator transistor (TR2). The emitter of the oscillator transistor is coupled to ground through resistance 73. Thus, a series path is completed for current from the primary control bus 31 through the two transistors to ground. The base of the oscillator transistor (TR2) is coupled to the mode switch 29 which is grounded in the AM position. Grounding the base of TR2 removes its forward bias, cutting it off and precluding current through both the mixer and oscillator transistors of the FM tuner. When the selector switch 29 is set to the FM position, the base of oscillator transistor TR2 has a positive potential, forward biasing the input of the junction of the transistor and permitting current to flow through both TR2 and the mixer transistor TR1 and activating the tuner.

Automatic frequency control of the FM tuner is also readily achieved. It is well known that the frequency of a transistor oscillator may be modulated by adjustment of its collector-base potential. The AFC circuit is arranged to operate on this prin-

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ciple in response to changes in potential on the primary control bus 31. The base of the FM mixer transistor (TR1) is d.c. coupled to the primary control bus through resistance 71. By virtue of the previously noted d.c. connection between the emitter of TR1 and the collector TR2, any changes in potential on the control bus are transferred through the input junction of TR1 and the collector of TR2. Thus, the voltage on the primary control bus less the drop across the input junction of TR1 is applied to the collector of TR2. Since the voltage on the control bus varies as a function of the frequency offset of the detected FM signal, it may be used to correct the oscillator frequency automatically to achieve optimum tuning pursuant to the automatic frequency control function.

The circuit of the current amplifier 36, controlled current source 54, and the 1.2 volt temperature compensated source 53 are illustrated in detail in Figure 2. Their function is to stabilize the gain of the IF amplifier and the tuning of the automatic frequency control network as against ambient or self-induced temperature changes. Without such a provision, the voltage on the primary control bus may vary 200 or 300 millivolts when a substantial temperature variation takes place. Thus, both gain and tuning can be noticeably affected by such temperature variations. In the event that the FM tuner is in a high temperature condition when turned off, without such compensation it may not re-lock onto the prior station or it may lock onto a different station altogether when turned back on in a cold condition.

The foregoing and several other temperature problems are avoided by the use of temperature compensated 1.2 volt source 53. The current amplifier 36 and controlled current source 54 consist of four transistors Q11, Q17, Q22, Q23. Q17 is a laterally formed PNP transistor whose emitter is returned to the 6 volt B+ bus and whose collector is coupled to the primary control bus for energizing the bus. A small latching current is provided to the same bus by a transistor Q51 (current source 59 of Figure 1) for ensuring start up of the current amplifier. The base of current amplifier transistor Q17 is coupled to the collector of control transistor Q22. The base of Q22 is coupled to the pad 8 at which both the AM and FM outputs appear. By these connections, transistor Q22 effects a control on transistor Q17 proportional to the average level of the detected signal. The second control transistor (Q23) has its collector coupled to the base of current amplifier transistor Q17. Q23, as previously noted, is arranged to be switched on or off as a function of the mode setting of

the radio receiver. The emitter of Q23 is returned through its emitter load resistance to the third control bus 33 where it assumes either a ground potential or the potential of the secondary control bus, dependent on the setting of selector switch 30. The base of Q23 is connected to the temperature compensated 1.2 volt output supply 53. The supply 53 is a band gap regulator in which Q61, D8, R56, R57 and R58 are the controlling components. Their parameters are selected to produce an output voltage with a zero temperature coefficient. The temperature compensated supply is energized through a connection to the B+ (6 volt) supply. A connection is also provided to the amplifier 44 for deriving a 1.2 volt start-up potential for this supply. In the FM mode, the recited connections to the temperature stabilized voltage supply provide a very accurate control over transistors Q23, Q17. Thus by stabilizing the potential on the primary control bus 31, both IF gain and oscillator frequency are stabilized for FM operation. Also in the FM mode of operation, the temperature compensated supply 53 is used to stabilize the current levels in the AM-FM detector (Q18, Q19) and the FM audio block (Q24, Q27) to stabilize the resultant audio output.

In the AM mode, the temperature compensated supply 53 provides a convenient on-the-chip-source of voltage for effecting a delay in the AGC action on the AM mixer. The mixer AGC circuit is best understood by reference to Figure 2A. The AGC delay circuitry produces an initially slow rate of gain withdrawal from AM mixer 23 until a given point is reached and then the rate of gain withdrawal is increased. The delay circuitry comprises resistances R16, R17, R18 and transistor Q35. Resistances R18 and R16 are serially coupled between ground and the emitters of the lower rank transistors Q30, Q31 of the AM mixer. Transistor Q35 has its base coupled via bus 60 to the 1.2 volt temperature compensated source 53 and its collector coupled to the 6 volt B+ bus. Its emitter is coupled through resistance R17 to the connection point between R16 and R18. The transistor Q35 may be regarded as a voltage reference equal to 1.2 volts less the V_{be} drop of the transistor.

The AGC characteristic of the mixer circuitry may be explained using Thevenin's theorem. The lower rank mixer transistors (Q30, Q31) may be regarded as having an emitter load consisting of a virtual resistance R16' in series with a virtual voltage V₁. R16' is defined to be:

$$R16' = R16 + \frac{R17 R18}{R17 + R18} \quad (3)$$

and V₁ is defined to be:

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$$V_1 = \frac{0.5V R18}{R18 + R17} \quad (4)$$

where 0.5 volts represents the (1.2 volt - 5 Vbe) at transistor Q35.

These produce the double slope AGC characteristic mentioned above. For low input signal levels, the voltage of AGC bus 32 and 33 will be maximum, initially about 1.2 volts. The mixer current will be determined primarily by R16' and the voltage difference (initially about 0.3V) between the emitter and V_1 . As the signal increases, the AGC bus voltage drops to the point where the degenerative effect of R16' is no longer significant. At this point, the gain is then determined primarily by the base emitter log characteristic of the lower rank transistors Q30, Q31. In this high signal region, the g_m and accordingly the gain of the mixer reduces at a faster rate with increasing signal than when the degenerative effect was predominant. The foregoing double slope is potentially present in the IF amplifier. However, because of the pre-bias attributable to V_1 , the "knee" of the AGC characteristic (the point at which maximum slope starts) occurs in the mixer at a 200 millivolt higher AGC bus potential than it would occur in the IF amplifier. When the AGC control range is properly limited, the IF amplifier does not go beyond the "degenerative" region or enter the "knee" of its AGC characteristic. Beginning with the lowest signal level and then progressively increasing the signal level, but still in the low signal level domain, causes a reduction in the gain of the mixer less than that in the I.F. amplifier, and therefore one may regard the gain reduction in the mixer as being delayed with respect to the IF amplifier.

The mixer AGC action also entails a property of the four quadrant multiplier configuration. As seen in Figure 2, the AM oscillator 24 is also subjected to AGC action. Thus, when strong signals are present, a reduction in local oscillator injection takes place, bringing about a proportionate reduction in conversion gain and producing further extension in the AGC control range.

The foregoing mixer configuration is particularly advantageous in that the AM mixer can handle very large overload signals with low (less than 10%) total harmonic distortion. This arises because at very high overload signals, the mixer becomes self-biased from rectification of the input signal in the base emitter junction of transistor Q30. The IF output filters for the mixer remove the unwanted harmonics, and the eventual demodulated audio signal is relatively undistorted.

Reference is made to our copending patent application No. 42491/76 (Serial No.

1574008) from which this application has been divided and which claims an IF amplifier as disclosed herein, and to patent application No. 7923095 (Serial No. 1574010) which claims a combination of 70 current sources as disclosed herein.

WHAT WE CLAIM IS:—

1. An intermediate frequency (IF) amplifier for a radio receiver capable of receiving in the AM mode or FM mode, the IF amplifier being d.c. coupled and arranged to amplify signals at frequencies both in a frequency range centered on a higher FM, IF, and centred on a lower AM IF, the amplifier comprising:

(a) a plurality of consecutive stages, said consecutive stages considered collectively, having wide band a.c. gain embracing both said ranges, each such consecutive stage including an emitter coupled transistor pair comprising an input transistor and an output transistor, there being provided for each such pair an emitter-resistor arranged to pass emitter currents of both transistors of its respective pair, those ends of said emitter-resistors which are remote from the respective emitters being connected together and to an earth-line or earth-point,

(b) a primary bus through which is to be applied d.c. collector operating current to the individual transistors of said consecutive stages,

(c) a secondary bus for passing d.c. base current to the output transistor of each said pair and for applying degenerative feedback to provide balanced biasing of each said transistor pair,

(d) means for establishing said secondary bus at a potential which is a function of the potential of said primary bus and for applying said degenerative feedback to said secondary bus, including

(1) a collector load resistance connected between said primary bus and the collector of the output transistor of the last of said consecutive stages, and

(2) a degenerative feedback resistance having one end connected to the collector of the output transistor of the last of said consecutive stages and the other end connected to the base of said output transistor of the last of said consecutive stages and to said secondary bus,

wherein the said collector load resistance and feedback resistance, and the circuits associated with said consecutive stages are so designed or selected, that

(A) when there is applied via said primary bus the aforesaid d.c. collector operating current in the FM mode at a first value lying in a first range of current values, the primary bus is at a first d.c. potential, lying in a first range of potential values, with res-

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$$V_1 = \frac{0.5V R18}{R18 + R17} \quad (4)$$

where 0.5 volts represents the (1.2 volt - 5 Vbe) at transistor Q35.

These produce the double slope AGC characteristic mentioned above. For low input signal levels, the voltage of AGC bus 32 and 33 will be maximum, initially about 1.2 volts. The mixer current will be determined primarily by R16' and the voltage difference (initially about 0.3V) between the emitter and V₁. As the signal increases, the AGC bus voltage drops to the point where the degenerative effect of R16' is no longer significant. At this point, the gain is then determined primarily by the base emitter log characteristic of the lower rank transistors Q30, Q31. In this high signal region, the g_m and accordingly the gain of the mixer reduces at a faster rate with increasing signal than when the degenerative effect was predominant. The foregoing double slope is potentially present in the IF amplifier. However, because of the pre-bias attributable to V₁, the "knee" of the AGC characteristic (the point at which maximum slope starts) occurs in the mixer at a 200 millivolt higher AGC bus potential than it would occur in the IF amplifier. When the AGC control range is properly limited, the IF amplifier does not go beyond the "degenerative" region or enter the "knee" of its AGC characteristic. Beginning with the lowest signal level and then progressively increasing the signal level, but still in the low signal level domain, causes a reduction in the gain of the mixer less than that in the I.F. amplifier, and therefore one may regard the gain reduction in the mixer as being delayed with respect to the IF amplifier.

The mixer AGC action also entails a property of the four quadrant multiplier configuration. As seen in Figure 2, the AM oscillator 24 is also subjected to AGC action. Thus, when strong signals are present, a reduction in local oscillator injection takes place, bringing about a proportionate reduction in conversion gain and producing further extension in the AGC control range.

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1574008) from which this application has been divided and which claims an IF amplifier as disclosed herein, and to patent application No. 7923095 (Serial No. 1574010) which claims a combination of 70 current sources as disclosed herein.

WHAT WE CLAIM IS:—

1. An intermediate frequency (IF) amplifier for a radio receiver capable of receiving in the AM mode or FM mode, the IF amplifier being d.c. coupled and arranged to amplify signals at frequencies both in a frequency range centered on a higher FM, IF, and centred on a lower AM IF, the amplifier comprising:

- (a) a plurality of consecutive stages, said consecutive stages considered collectively, having wide band a.c. gain embracing both said ranges, each such consecutive stage including an emitter coupled transistor pair comprising an input transistor and an output transistor, there being provided for each such pair an emitter-resistor arranged to pass emitter currents of both transistors of its respective pair, those ends of said emitter-resistors which are remote from the respective emitters being connected together and to an earth-line or earth-point,
- (b) a primary bus through which is to be applied d.c. collector operating current to the individual transistors of said consecutive stages,
- (c) a secondary bus for passing d.c. base current to the output transistor of each said pair and for applying degenerative feedback to provide balanced biasing of each said transistor pair,

(d) means for establishing said secondary bus at a potential which is a function of the potential of said primary bus and for applying said degenerative feedback to said secondary bus, including

(1) a collector load resistance connected between said primary bus and the collector of the output transistor of the last of said consecutive stages, and

(2) a degenerative feedback resistance having one end connected to the collector of the output transistor of the last of said consecutive stages and the other end connected to the base of said output transistor of the last of said consecutive stages and to said secondary bus,

wherein the said collector load resistance and feedback resistance, and the circuits associated with said consecutive stages are so designed or selected, that

(A) when there is applied *via* said primary bus the aforesaid d.c. collector operating current in the FM mode at a first value lying in a first range of current values, the primary bus is at a first d.c. potential, lying in a first range of potential values, with res-



pect to earth and the IF amplifier exhibits a first value of overall IF amplifier a.c. gain, and

(B) when there is applied *via* said primary bus the aforesaid d.c. collector operating current in the AM mode at a second and different value lying in a second range of current values, the primary bus is at a second and different d.c. potential, lying in a second range of potential values, with respect to earth, and the IF amplifier exhibits a second and different value of overall IF amplifier a.c. gain lying in a range of gain values,

(C) the second value of gain being variable in accordance with the d.c. potential on said secondary bus, as derived from said potential of second value on said primary bus and as transmitted *via* said secondary bus to said output transistors, and wherein each said transistor pair comprises a conductor-connection from the primary bus to the collector of the input transistor of the pair, a collector load resistor connected between the primary bus and the collector of the output transistor of the pair, a conductor-connection which interconnects the emitters of the transistors of the pair and also the non-earthed end of the respective said emitter-resistor, and a conductor-connection from the collector of the output transistor of the pair to the base of the input transistor of the next higher stage, and the bases of said output transistors are conductor-connected to said secondary bus, and further wherein for the transistor pairs there is a uniform ratio of resistance value of the collector load resistor of the output transistor of any pair to the resistive value of the commoned emitter load resistor of such given pair, such uniform ratio being substantially one to one.

2. An IF amplifier as claimed in claim 1, wherein the IF amplifier's transistors and their associated circuitry are further so designed or selected, that when there is applied in the AM mode *via* said primary bus d.c. potential in the said second potential range, which d.c. potential contains a dynamic d.c. component corresponding to the amplitude of the AM IF modulated carrier delivered by said IF amplifier, the overall gain of the IF amplifier is automatically controlled by such dynamic d.c. component *via* said secondary bus, so that the a.c. carrier plus modulation output signal delivered by the IF amplifier exhibits relatively small changes in amplitude with relatively large amplitude changes of the a.c. carrier plus modulation input signal to the IF amplifier.

3. An IF amplifier as claimed in claim 1 or claim 2, comprising an additional IF amplifier stage itself comprised of an emitter-coupled transistor pair, with emitters connected together and *via* a d.c. passing

connection to earth, the base of the input transistor of the additional pair being conductor-connected to the collector of the preceding output transistor of the highest order stage of the aforesaid consecutive stages, the base of the output transistor of the additional pair being conductor-connected to the secondary bus, the together-connected emitters of the additional stage being connected to earth *via* a current source,

4. An IF amplifier as claimed in claim 3, wherein the therein recited current source is formed of an emitter circuit for the final stage, said emitter circuit comprising first and second final stage emitter circuit semiconductor diode devices connected *inter se* in series and poled to conduct current in the same direction from a d.c. power supply line, one electrode of the latter first diode device being connectible to that d.c. power supply line and the correspondingly other electrode of the latter second diode device being connected to a node-point, from which is further connected a resistive connection to a point of primary reference potential such as earth, a first final stage emitter circuit current source comprising its own first current-source transistor which has a first conductivity type which is opposite to the second conductivity type of the input and output transistors, the emitter of the first final stage emitter circuit current-source transistor being connected to an end of a resistance having another end connectible to said d.c. power supply line, its base being connected to the last-mentioned node-point, and its collector being connected to the base of a second final stage emitter circuit current-source transistor which is of second conductivity type and which is included in the latter said current source between said emitters and earth, the collector of the second current-source transistor being connected to the commoned emitters of the input and output transistors, its emitter being connected *via* a resistance to said point of primary reference potential, and its base being further connected *via* the series combination of a third semiconductor diode device and of a resistance to said point of primary reference potential, the latter third diode device being poled to conduct current in the same direction as the direction for the first and second diode devices.

5. An IF amplifier as claimed in claim 4, wherein the values of the resistance in the emitter circuit of the second final stage emitter circuit current source, and of the resistance contained in the series combination are substantially equal.

6. An IF amplifier as claimed in any one of claims 1 to 5, wherein integrated together are the transistors, semiconductor diode devices, resistances, resistors, resistive connections, and current source, as recited in

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the respective ones of claims 1 to 5.

7. An IF amplifier as claimed in claim 1 and substantially as described with reference to Figs. 2A and 2B of the accompanying drawings.

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