In addition to the above requirements it is essential that feedback through the anode-to-grid capacitance of the valve, should be kept small. This usually calls for a strict limit on the maximum usable transfer impedance obtained in an i.f. transformer when applied with any particular valve type. With the EF41, the recommended maximum design centre transfer impedance for the i.f. transformer is 21 kΩ at 10.7 Mc/s, taking into account the added effective anode-to-grid capacitance in the valveholder, and assuming identical impedances in grid and anode circuits.

Table 1 gives a summarized performance of the transformers used in this tuner. All the values quoted were measured in circuit.

The two EF41 valves operate with a mutual conductance of 2.3 mA/V, and from the relevant impedances given in Table 1, it can be calulated that the total i.f. gain, from the control grid of V3 to the anode of V4 will be 64 dB. Actual measurement showed a slightly lower value.

Measurement of the overall bandwidth of the first and second i.f. transformers gave approximately 210 kc/s for 3 dB, and 600 kc/s for 20 dB, attenuation. The response curve is flat for approximately 70 kc/s, with a slight dip at the centre frequency.

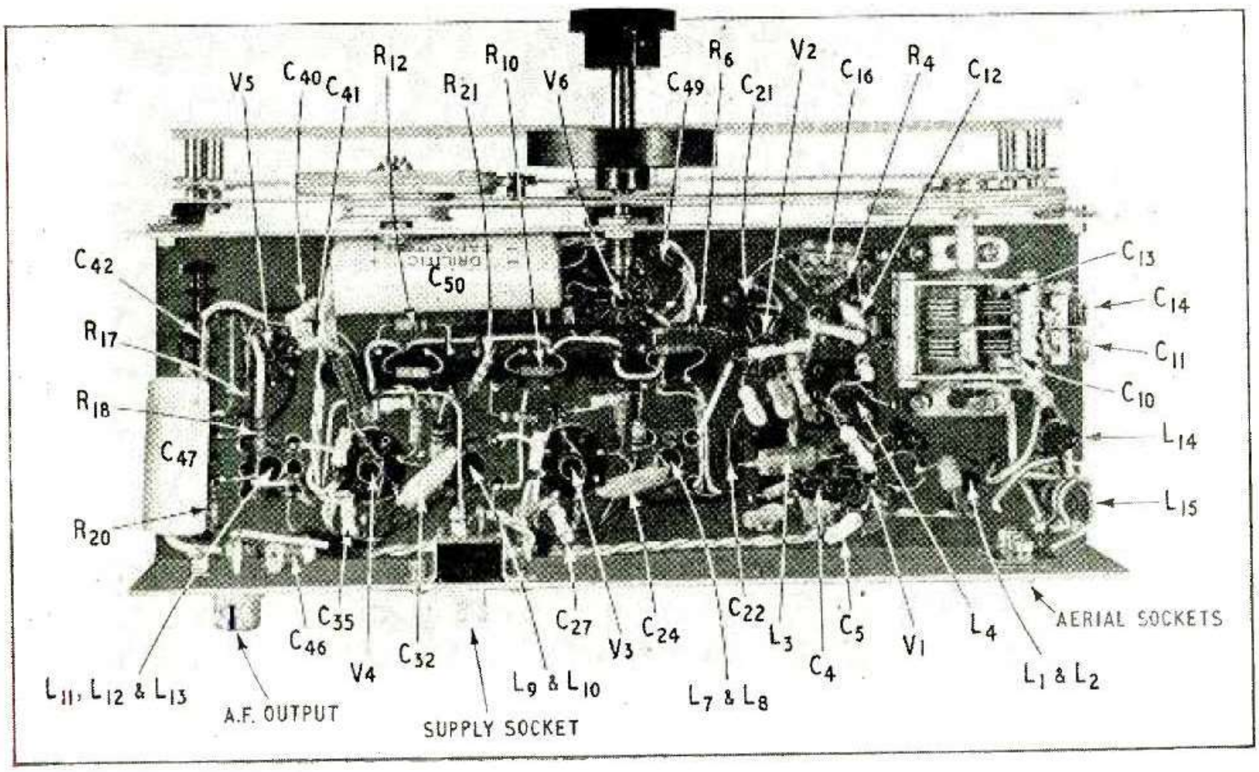
The coils for the i.f. transformers are wound on common formers, details of which are given later in the Appendix. An inherent drawback in this method of construction is that movement of the dust cores can materially alter the coupling factor if the primary and secondary windings are, by necessity, brought too close together. This is to some extent eliminated in the design presented here, by separating about 25% of the total windings on the coils, so as to form small coupling coils at the earthy end of each winding. Thus the dust cores are kept at least 15 mm distant in the main body of the windings and little measurable difference in the coupling factor is obtained when the transformers are tuned to ± 1 Mc/s of the correct working centre frequency. The unloaded Q factors of the coils are about 90, with the exception of L_{12} which is approximately 85.

As previously mentioned, on high signal levels V4 is driven into appreciable grid current, and the derived bias voltage developed across R_{11} and R_{12} is used as semi-automatic gain control. Positive peaks of amplitude modulation appearing on the carrier wave are therefore clipped in the grid circuit. With V4 primarily designed as an amplifier, a very high input voltage to the grid is required before saturation occurs. Therefore with only partial limiting occurring, the valve does not deal completely with positive—or negative-going amplitude variations of the carrier. For similar reasons partial limiting may give only restricted elimination of impulsive interference. The time constant of the grid circuit of V4 has been set at 25 microseconds to deal with the upper frequency limits of amplitude variations in the carrier. The small changes in the input capacitance of V4 due to limiter action in the grid circuit and of V3 due to the restricted range of applied bias voltage were not found to introduce any serious deterioration in the required performance of the band-pass filters. Further, harmonics produced by limiter action do not usually cause trouble, as they will be tuned out in the anode circuit of V4.

Ratio Detector—A balanced ratio detector circuit incorporating a double diode (V5) is used in this tuner. To give optimum a.m. rejection under working conditions, R_{17} should be adjusted for each individual circuit and is specified here as a nominal value.

The value of a.m. rejection measured in the circuit was 46 dB at the centre frequency (10.7 Mc/s) for 30V r.m.s. of i.f. voltage at the anode of V4, falling to

View of underside of chassis with some of the more prominent components identified.



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28 dB for ±75 kc/s detuning of the signal. Similarly for 20 and 10V r.m.s. of i.f. signal, the values were 34 and 26 dB respectively, with corresponding values of 22 and 17 dB for ± 75 kc/s detuning. These figures include limiter action produced by V4. The peak separation of the "S" shaped detector curve is 320 kc/s.

Measurement of the tuning characteristic is advantageous in a prototype f.m. receiver, in order to examine the side responses which are inherent in most f.m. detector systems. These are shown in Fig. 3, where the tuning characteristic of the unit is plotted for various values of input signal.

These characteristics can be regarded as typical for a receiver equipped with a ratio detector circuit. The side responses are shown at about ± 200kc/s from the centre frequency. To a certain extent these side responses are controlled by the selectivity characteristic of the preceding i.f. stages, and also by the action of a.g.c. In general, receivers designed with a rounded-top overall i.f. response curve, and a comparatively wide peak separation in the detector system help to reduce side responses and produce a peak in the audio output, when the signal is in tune. It may be noted in passing that, with the Foster-Seeley detector circuit and limiter valves, the side responses may be of a higher value than the main signal response. Although the side responses show a comparatively high value in the graph at the larger signal levels, they are in fact hardly noticeable when tuning through the signal.

The audio output from the detector is taken through the 50-microsecond de-emphasis network R_{16} and C_{45}, and coupling capacitor C_{46} to the a.f. output socket. When the output from the tuner is fed to an audio amplifier it is recommended that the amplifier input impedance be not less than 500 kΩ. For use with the pre-amplifier[3] designed for use with the 20-watt EL34 circuit[2] and with other pre-amplifiers of similar input impedance and sensitivity it is recommended that a correction circuit (Fig. 4) be used to obtain the required input impedance and attenuation.

Tuning Indicator.—An optional tuning indicator using a Mullard EM80 is fitted. The bias voltage for this valve is derived from the ratio detector circuit.

Overall performance.—The total gain of the prototype tuner from the aerial terminals to the anode of V4 was approximately 130 dB for a small signal at 94 Mc/s. When coupled to a Mullard 5-valve 10-watt amplifier, the average sensitivity over the band for 50 mW output was 1.2μV with a signal of 22.5 kc/s deviation. The average input signal over the band for 500 mV audio output is approximately 12 to 15μV.

Oscillator radiation.—The average oscillator voltage measured at the aerial terminals was 350 μV for the fundamental oscillator frequency and 75 μV for the 2nd harmonic. The average radiated field strengths over the band are 40 μV per metre and <15 μV per metre respectively at a distance of 10 metres from the measuring aerial.

Constructional details.—The accompanying photographs show the main layout of the tuner. A chassis of 16 s.w.g. aluminium, dimensions 10 in × 3½ in, with 2 in depth, is used. With the exception of the valves, i.f. transformers, aerial and oscillator coils and scale assembly, all components are mounted underneath the chassis.

A balanced heater circuit is used. This enables the tuner to be connected to the centre-tapped heater supply of either of the amplifier circuits previously

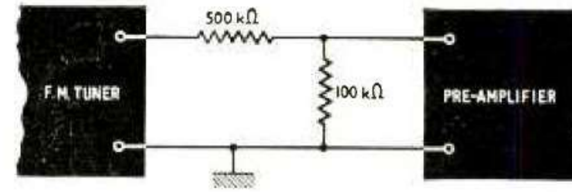

Fig. 4. Simple attenuator recommended for use with amplifiers of high sensitivity and input impedance less than 500kΩ.

referred to[1,2]. Adequate r.f. decoupling of the heater supply lead is essential, in particular to prevent harmonics from the detector from reaching the earlier stages. The ninth harmonic of the i.f. can be particularly troublesome, as this falls in the centre of the tuning range. Strict attention should be paid to the general decoupling of the valve electrodes, and to the tuned circuits. The relevant decoupling capacitors, should be returned to, or very near to, the cathode-to-chassis connection of the valve concerned, with the shortest possible leads. It is also essential that C_{16} should have a short connection to chassis.

The tuner requires an h.t. supply of 200 V at approximately 37 to 40 mA and a heater supply of 6.3 V at 1.6 A. Where the h.t. supply is obtained from an amplifier and exceeds 200 V the necessary dropping resistance should be included in the amplifier itself.

To minimize oscillator drift during the warming up period, C_{12} should be of the negative temperature coefficient type, a component of temperature coefficient 750 parts per million being suitable. This will help to keep the long term oscillator drift to a minimum. In the prototype, C_{14} and C_{16} were formed of a 6.8pF capacitor in parallel with a 1.25-10pF trimmer to make up the nominal total. The tap on the r.f. coil is arranged to be at 0.4 of the total number of turns, counting from the earthy end. Optional i.f. traps L_{14}, C_{51} and L_{15}, C_{52}, have been incorporated in the aerial circuit for use where a high degree of i.f. rejection is considered essential. In most cases they may be found unnecessary.

Neatness in wiring is essential. In particular, in the i.f. stages, components should not be piled over the top of the valveholder as this may lead to an increase of effective anode-to-grid capacitance.

Alignment.—The correct alignment of an f.m. receiver calls for the use of some expensive equipment, but good results can be obtained by using only an a.m. signal generator, covering Band II (87.5-100 Mc/s) and the intermediate frequency of the tuner (10.7 Mc/s). As the first two i.f. transformers are overcoupled, it is essential to damp the transformers whilst they are being tuned, otherwise unsymmetrical response curves may result. A resistor of about 5 kΩ is suitable for this purpose and it should be placed across the grid circuit tuned winding, when the anode circuit is being tuned, and vice versa. The resistor can be temporarily held on with a touch of solder.

Connect the signal generator output (10.7 Mc/s) to the control grid of V4 and tune L_{11} for maximum deflection either in the tuning indicator or on a high resistance voltmeter (20 kΩ/V, 10 V scale) across C_{47}. Transfer the generator in turn to the grid of V3, and the centre-tap point of L_5. Tune L_9, L_{10} and L_7 and L_8 respectively for maximum deflection, using the damping resistor for the coils as before.

To eliminate considerable trial and error in the alignment of the r.f. and oscillator circuit, some approximate values of the correct trimmer settings

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are given. C_{16} can be set initially at about 10 pF, and C_{14} to 12 pF, with the dust core of L_6 tuning in the *base end* of the coil away from L_5. C_{11} is set at approximately 5 pF. The bridge circuit may be balanced by connecting an r.f. valve voltmeter from the tap point of L_4 to earth, and adjusting C_{16} for minimum oscillator voltage. While this operation is being done, the main tuning gang should be set with the vanes about half-way between minimum and maximum capacitance. If an r.f. valve voltmeter is not available, a rough and ready, but quite effective method of obtaining balance is to short-circuit the tap on L_4 to earth and observe the change in grid current through R_5 (on $50\mu A$ scale). C_{16} is then adjusted until the change in grid current on short-circuiting L_4 to earth is a minimum.

With the signal generator connected at the aerial terminals and the tuning gang at maximum capacitance apply a signal of 87 Mc/s, and tune L_6 dust core so that a maximum deflection is indicated in the tuning indicator or voltmeter. Re-tune the signal generator to 100 Mc/s and adjust C_{14} for optimum output with the tuning gang at minimum capacitance. These settings may need to be checked a number of times to give the correct frequency range for the oscillator.

Re-set the signal generator to 91 Mc/s and adjust L_1 dust core for maximum output. Adjust C_{11} for maximum output at 98 Mc/s and finally set L_2 dust core for maximum output at 93-94 Mc/s. The dust core of the aerial coil should also be at the base end of the former. To align the i.f. traps apply a comparatively large input signal of 10.7 Mc/s to the aerial terminals, and tune L_{14} and L_{15} for minimum indicated output. With the signal generator connected again to V4 grid and with the signal of 10.7 Mc/s adjust L_{12} core, for zero d.c. voltage across C_{44}. This ensures that the ratio detector circuit is reasonably well balanced.

REFERENCES

1 "Mullard 5-valve 10-watt High Quality Amplifier Circuit," published by Mullard Ltd.
Also briefly described in:
"Inexpensive 10-watt Amplifier," *Wireless World*, August 1954.
"A High-quality Ten-Watt Audio Amplifier," by D. H. W. Busby and W. A. Ferguson. *Mullard Technical Communications*. Vol. 1, No. 9. Nov., 1954.

2 "Design for a 20-watt High-Quality Amplifier, 2—Constructional Details and Performance," by W. A. Ferguson. *Wireless World*, June 1955.

3 "Design for a Pre-amplifier, for use with a 20-watt High-quality Amplifier." by D. H. W. Busby. *Wireless World*, July 1955.

(*Appendix—Coil Winding Data—on next page*)

COMPONENTS LIST FOR F.M. TUNER

Capacitors

C_1	120 pF ±20% (C)
C_2	5 pF ±10% (C or SM)
C_3	2,200 pF ±20% (C)
C_4	1,500 pF ±20% (C)
C_5, C_6	2,200 pF ±20% (C)
C_7	120 pF ±20%
C_8	1,500 pF ±20%
C_9	33 pF ±5%
C_{10}, C_{13}	2/27 pF Two-gang variable (Jackson U101 S-S)
C_{11}	3-15 pF (nominal) (composed of 1.25—10pF trimmer, Wingrove & Rogers, Type C32.01 + 6.8 pF, SM)
C_{12}	27 pF ±5% (optional n.t.c. 750 parts per million)
C_{14}	3–15 pF (nominal)
C_{15}	120 pF ±20% (C)
C_{16}	3–15 pF (nominal)
C_{17}	22 pF ±10% (C)
C_{18}	22 pF ±5% (C)
C_{19}, C_{20}	2,200 pF ±20% (C)
C_{21}	2,200 pF ±20% (C)
C_{22}	0.01 μF Met. paper
C_{23}	12 pF ±5%
C_{24}	150 pF ±20%
C_{25}, C_{26}, C_{27}	2,200 pF ± 20% (C)
C_{28}, C_{29}	0.01 μF Met. paper
C_{30}, C_{31}	12 pF ± 5% (C or SM)
C_{32}	47 pF ±20%
C_{33}, C_{34}, C_{35}	2,200 pF ±20%
$C_{\,6}$, C_{37}	0.01 μF Met. paper
C_{38}	12 pF ± 5% (C or SM)
C_{39}	47 pF ±5% (C or SM)
C_{40}, C_{14}	2,200 pF ±20% (C)
C_{42}, C_{43}, C_{44}	330 pF ±5%
C_{45}	500 pF (SM) ±10%
C_{46}	0.02 μF (T.C.C. "Metalmite.")
C_{47}	4 μF 150 V.W. electrolytic
C_{48}, C_{49}	0.01 μF Met. paper (for optional tuning indicator)
C_{50}	8 μF 350 V.W. electrolytic
C_{51}, C_{52}	47 pF ± 5% (C) (for optional i.f. traps)

C — Ceramic. SM — Silvered mica

Resistors (all resistors ½ watt Dubilier "BTS" type)

R_1	470kΩ ± 20%
R_2	1,200Ω ± 20%
R_3	68kΩ ± 10%
R_4	15kΩ ± 10%
R_5	100kΩ ± 10%
R_6	27kΩ ± 10%
R_7	3,300Ω ± 20%
R_8	1.0MΩ ± 20%
R_9	82kΩ ± 10%
R_{10}	1,200Ω ± 20%
R_{11}	470kΩ ± 20%
R_{12}	1.0MΩ ± 20%
R_{13}	82kΩ ± 10%
R_{14}	1,200Ω ± 20%
R_{15}	47Ω ± 10%
R_{16}	100kΩ ± 10%
R_{17}	1,200Ω ± nominal ± 5%
R_{18}	2,700Ω ± 5%
R_{19}, R_{20}	15kΩ ± 5%
R_{21}, R_{22}	470kΩ ± 20% (For optional tuning indicator)
R_{23}	470kΩ ± 20% (For optional tuning indicator)

Other Components

Miniature tag strips—British Moulded Plastics Type A 5556
Stand-off insulators—Wingrove and Rogers. Type TS1-01/1.
Scale and drive assembly—Jackson, Type SL15.

Valves

V1	Mullard EF85
V2	Mullard EF80
V3, V4	Mullard EF41
V5	Mullard EB91
V6	Mullard EM80 (Optional tuning indicator)

Coils

Aerial transformer L_1, L_2	Denco 510/AE
R.F. choke L_3	Denco 510/RFC
R.F. coil L_4	Denco 510/RF
Oscillator coil L_5, L_6	Denco 510/OSC
1st i.f. coil L_7, L_8	Denco 510/IFT.1
2nd i.f. coil L_9, L_{10}	Denco 510/IFT.2
Ratio detector Transformer, L_{11}, L_{12}, L_{13}	Denco 510/RDT
I.F. traps L_{14}, L_{15}	Denco 510/IFF

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