RF CIRCUIT DESIGN

Third in the series, this article discusses aspects of good VHF preamplifier design, before proposing a practical circuit that enables reception of FM broadcast signals hitherto lost in noise.

VHF PREAMPLIFIER

Some of the important aspects in aerial amplifier design have already been covered in *Elektor India* April 1986 issue, along with the prerequisites for successful VHF filter realization. While the points discussed in that article remain fully valid, the present article aims to look at the most important technical characteristic of any VHF preamplifier stage: its noise figure.

While many of today's FM tuners have very sophisticated tuning control systems and excellent stereo demodulation, the design of up-to-date RF amplification and first mixer sections often deplorably lags behind. Since it is certainly not advisable to embark upon a complete reshuffle of the proprietary RF parts in the receiver front end, an add-on preamplifier stage of good design may prove helpful in updating the receiver performance to a considerable degree. Moreover, as the above mentioned article already pointed out, a VHF aerial booster should not be mounted in the receiver, but at the other end of the downlead coax cable, at the one and only place where it is effective; direct at the aerial connections (masthead mounting).

Noise

There are a number of basic considerations to go with design and construction of an RF preamplifier stage, if this is to operate in the very high frequency (VHF) range, generally referred to as 50...300 MHz. A section of this band is of special interest for this article, namely the FM broadcast band, which extends from 88 to 108 MHz; while being quite crowded with local stations in most built-up areas, only few stations may be received in rural districts. This is due to the straight line propagation characteristics of the RF waves at these frequencies, which makes it impossible to receive over-the-horizon stations, except during special weather conditions.

A typical daytime FM-band spectrum (= survey of signal strengths within a certain frequency band) may look very much as sketched in Fig. 1a; there are a number of very strong transmissions, as well as relatively weak and also nearly invisible (i.e. inaudible) ones, sometimes quite close to one another. This spectrum is purely hypothetical, however, since it is a representation of relative signal strengths at the aerial connections, i.e. without noise caused by any active electronic device. Obviously, the spectrum analyser itself would feature a certain amount of self-generated noise, but this has been disregarded for the sake of clarity. The low noise level N_i in Fig. 1a is, however, present at any

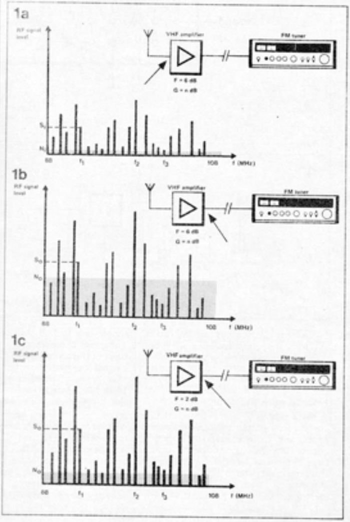


Fig. 1. Representation of FM band spectrum analyses showing that the noise factor of the preamplifier stage determines to a large extent the number of stations that can be made audible in the FM receiver.

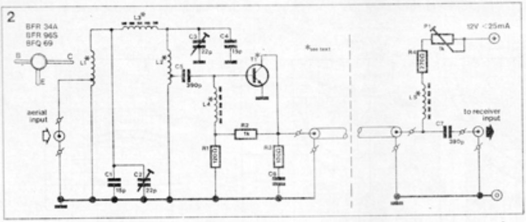


Fig. 2. Circuit diagram of the low-noise aerial amplifier with receiver-mounted supply parts.

VHF aerial, since this picks up a certain amount of atmospheric noise; the nature of this effect would lead us into theoretical physics, which is beyond the scope of this article. Spectrum analysis of the preamplifier output signal (Fig. 1b) reveals that while all signals have been amplified, a certain amount of additional noise is introduced by the aerial booster, to the effect that some signals have got lost underneath the noise threshold N_o and are, therefore, inaudible in the receiver. Since the amplifier noise output is not caused by amplification of the atmospheric noise level N_i (compare the signal levels of f_3 in Fig. 1a and 1b), level N_o must needs be generated by the amplifier itself; clearly, this is an undesirable effect. If we consider the effective signal strengths of, for instance, the transmission at f_1 in Fig. 1a as opposed to Fig. 1b, the total **noise factor** of the amplifier stage may be defined as the overall ratio of the output signal/noise ratio to the input signal/noise ratio, or

$$F=(S_o/N_o)/(S_i/N_i) \quad (1)$$

the **noise figure** may be calculated from F using

$$F_{dB}=10\log_{10}F \quad (2)$$

Clearly, S_o/N_o for f_1 is worse (lower) than the original S_i/N_i and this arises from the extra amount of noise generated by the amplifier. Were this device ideal, then

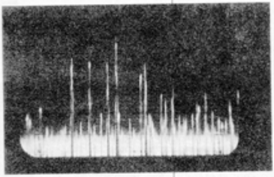
$$S_o/N_o=S_i/N_i \text{ or } F=1, \text{ or } F_{dB}=0\text{dB} \quad (3)$$

Unfortunately, no electronic device has been developed as yet for use in the ideal preamplifier, nor will it ever be developed, due to some basic laws of physics. However, modern SHF transistors are now readily available with noise figures as low as 1.5 dB at 1000 MHz, while Gallium Arsenide (Ga-As) FETs have been designed to achieve 2.8 dB at 12 GHz; however, the cost and circuit design complexity of these devices puts them well beyond the reach of the average home constructor.

The importance of a low preamplifier noise figure is evident after a comparison of Figures 1b and 1c; while its signal gain (amplification factor) is still ndB, the amplifier of Fig. 1c has a noise figure improved by 4 dB, which enables reception of signals that were inaudible with the $F=6$ dB amplifier of Fig. 1b. We may, therefore, establish the general rule that reception is improved with a lower preamplifier noise figure. Thus, designing for low noise should be a high priority issue.

So far, only the active device in the preamplifier has been held responsible for the noise addition, but it should be pointed out that this device can only attain its minimum noise contribution when supported by passive components that ensure thermal stability and low signal insertion loss at the amplifier input. It will stand to reason that any mismatch at the booster input will adversely affect (i.e. increase) the transistor noise figure as given in the manufacturer's data sheets.

No preamplifier stage, however low its noise figure, will be capable of reception improvement if the signals at the target frequency have been considerably attenuated before being applied to the first active device, either by downlead cable losses or a severe mismatch at the booster input. As the above mentioned article pointed out, however, the preamplifier input necessarily consists of a low-loss filter, which serves the dual function of an out-of-band signal attenuator and signal source to transistor input impedance transformer (source matching). It should be fairly obvious by now that the actual gain of the booster is far less important than its noise figure; if the former is some 10 dB higher than the downlead cable attenuation, adequate results are usually obtained; a gain of 15...20 dB is common for a single-transistor preamplifier stage.



Practical circuit

The circuit diagram of the present VHF preamplifier is shown in Fig. 2. The RF signal at the input is passed to the base of T_1 by a capacitance-tuned, inductive top-coupled, low insertion loss and source matching bandpass input filter with a −2 dB bandwidth of 20 MHz (88.. ..108 MHz). This is quite a mouthful for a basically simple filter that performs the functions outlined above. Note the taps on L_1 and L_2 to obtain impedance matching of the cable and the transistor respectively. Any of the listed transistor types may be used in the circuit, but the Type BFQ69 is preferable because of its extremely low noise figure. Since this transistor has been introduced only quite recently, however, it may prove difficult to get hold of.

The amplifier is fed by the receiver power supply over the downlead coax cable; the parts to the right of the dotted line are, therefore, mounted in the FM tuner. Decoupling parts L_5 and C_7 ensure that no RF signal is lost in the power supply. The amplifier bias setting is effected with P_1; depending on the transistor in use, this preset may be adjusted to find the right compromise between

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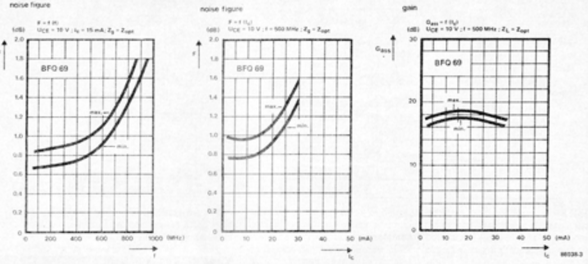

Fig. 3. Curves showing the characteristics of the new BFQ69 transistor. Note that the curves in Figures 3b and 3c refer to a test frequency of 500 MHz and not to the design frequency of the present preamplifier. (Siemens)

optimum noise figure (low current) or maximum amplification with acceptable intermodulation response (high current). For further details on the bias setting of RF preamplifier transistors, refer to *Elektor Electronics (UK)*, February 1980 issue. Fig. 3 shows three curves relevant to the novel BFQ69, a collector current of 15 mA appears to be suitable for a minimum noise figure of about 1 dB, which will bring the total noise figure of the present design in the 1...2 dB range with a Type BFQ69 fitted and the filter tuned to optimum input matching. However, the Types BFR34A and BFR96S will also ensure a noise figure that is usually far better than the average FM tuner specification in this respect.

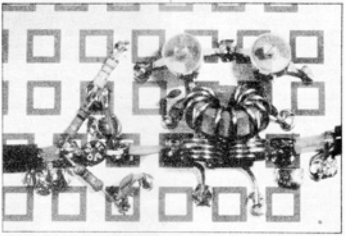

Fig. 4. This RF design is also fitted on the universal prototyping board 85000, available through the Readers Services.

The coils and chokes for the present design are wound as follows:

L_1 = 4 turns 20SWG (ϕ 1 mm) enamelled wire, close wound on dia. 6 mm, tap at 1.5 turns from earth.
L_2 = identical to L_1, but tap at 2.5 turns from earth.
L_3 = 11 turns 20SWG enamelled wire on toroid core Type T50-12 (Amidon).
L_4; L_5 = 4.5 turns 30SWG (ϕ 0.3 mm) enamelled wire through 3×3 mm ferrite bead.

For more information on inductor calculations and specifications, refer to last month's issue of *Elektor Electronics*.

Construction and alignment

The present amplifier is fitted on the universal RF board 85000 as shown in Fig. 4; not shown are the bias setting parts, since these are mounted in the receiver. After completion, the unit may be tested by tuning the receiver to a weak transmission at about 96 MHz and adjusting C_1 and C_2 for optimum reception. The collector current setting should be fairly uncritical; its precise effect on the amplifier performance can only be judged when a very stable and yet sufficiently weak transmission is being received and the input filter has already been correctly tuned. Finally, the preamplifier may be fitted in a suitable water-resistant case for masthead mounting, equipped with suitable coaxial sockets, and fixed to the aerial mast.

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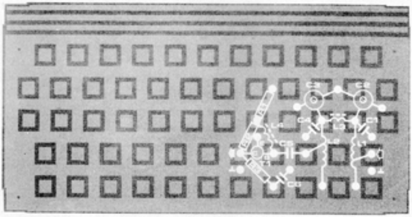

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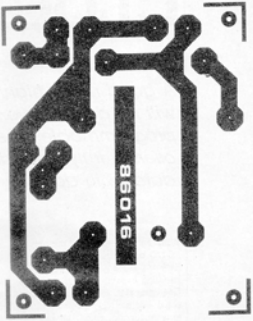

Subwoofer