In this edited excerpt from his forthcoming book, Ulrich Rohde, well known to readers for his many articles on receivers and other communication subjects, shares knowledge borrowed from commercial applications to improve noise handling capabilities in Amateur equipment.*

understanding and handling noise

Balancers, limiters, and squelch circuits enhance receiver performance

Pulse interference is often the limiting noise source for communication receivers on our HF and VHF bands. To understand how pulse interference affects performance — and before noise-reducing methods can be developed — it's necessary to understand the sources and types of interfering pulses. Although many solutions have been proposed since the early days of radio[1], a large part of this information is based on recent work.[2,3,4,5]

types of pulse interference

Noise can be viewed in both the time domain, with an oscilloscope, and in the frequency domain, using a spectrum analyzer.

The clicks that appear when a current is switched on or off represent the simplest form of an interference pulse (**fig. 1A**). In this case the energy in the interference spectrum is a function of the amplitude, slew rate, rise time t_r (i.e., the time it takes to build from 10 to 90 percent of final amplitude) and the repetition frequency. For wideband systems with a low-pass characteristic, the approximate formula $t_r = 0.3/\Delta f$ is valid, where Δf is the bandwidth in Hz and t_r is the rise time in seconds.

The theoretical vertical step with $t_r = 0$ (infinite rate of rise) has a spectrum that extends to infinity — i.e., the "click" would be heard at all frequencies. For finite pulse duration, t, the amplitude characteristic of the spectrum has a shape described as the sine integral (**fig. 1A**). As t increases, the frequency representation of the noise compresses — i.e., the minima in the spectrum are shifted toward lower frequencies. In actual circuits t_r will be at least 10 nanoseconds because of the presence of some line inductance. This results in the main spectrum components of this form of interference being below 30 MHz. Amplitudes are low and decrease above this frequency.

Commutator sparking is a special case of switching interference, in that a series of individual switching pulses are generated according to the type of machine, the number of poles, and speed (**fig. 1B**). Repetition frequencies up to several kHz can occur. This results in a higher spectral energy density than in the case of the single switch, proportional to this frequency factor. Thus, sometimes the rotating machine noise can be heard up to 30 MHz. The spectral amplitudes can increase by several orders of magnitude when arching occurs between the commutator and brushes. However, this does not occur often, since it would quickly destroy the commutator.

Ignition interference, which results from a high voltage discharge in a pressurized gas, has a repetition frequency of less than 1 kHz and a spectrum as indicated in **fig. 1C**. In the case of conventional circuit-breaker type ignition systems, the voltage amplitude is highest and the rise time shortest at low engine speeds. The breaker points, together with the high-voltage cables connected between the spark plugs and distributor, form resonant circuits which act like the

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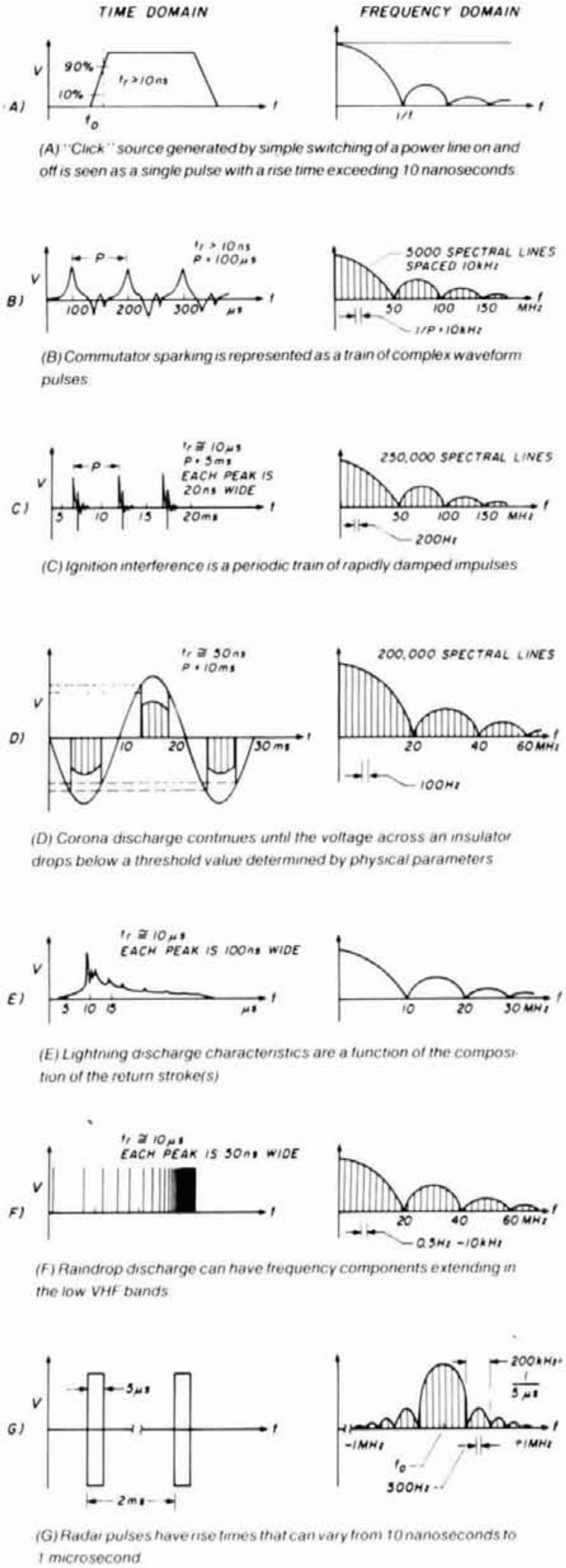

(A) "Click" source generated by simple switching of a power line on and off is seen as a single pulse with a rise time exceeding 10 nanoseconds.

(B) Commutator sparking is represented as a train of complex waveform pulses.

(C) Ignition interference is a periodic train of rapidly damped impulses.

(D) Corona discharge continues until the voltage across an insulator drops below a threshold value determined by physical parameters.

(E) Lightning discharge characteristics are a function of the composition of the return stroke(s).

(F) Raindrop discharge can have frequency components extending in the low VHF bands.

(G) Radar pulses have rise times that can vary from 10 nanoseconds to 1 microsecond.

fig. 1. Time and frequency domain representations of seven different types of "noise" interference. (Courtesy of M. Martin and *VHF Communications*, Spring, 1980.

spark transmitters used in the early days of radio communications. The oscillations decrease in an exponential manner.

Corona discharge occurs across defective insulators on high-voltage ac lines. A discharge can be ignited which, depending on the "quality" of the insulator, starts more or less below peak voltage and lasts until the voltage is reduced below a threshold which is always lower than the starting voltage. This process is repeated during the opposite half waves of the alternating voltage. (See **fig. 1D.**) In the case of a poor three-phase line, or even with a good line in very high humidity (for example, in fog), arcing of all three phases could result in an overlap of the burning times (which occur every 3.33 milliseconds for a 50-Hz line and every 2.78 milliseconds for a 60-Hz line.[6]

Lightning discharges account for what is called "atmospheric noise." In relatively flat terrain, 85 percent of all lightning strokes occur in a downward direction. The cloud involved is negatively charged and a current surge of up to 20 kA passes between it and the earth. Eighty percent of these lightning flashes have maximum currents of 50 kA.[7] It is, however, possible for several clouds to discharge via the same ionized path, in which case currents can exceed more than 200 kA. (See **fig. 1E.**) The duration of a lightning discharge can be between 0.1 milliseconds and 0.5 second, depending on how many subsequent surges are induced by the primary discharge.

Raindrop discharge, also known as precipitation static, results from charges transferred between a grounded antenna and statically charged raindrops. It causes a click-type interference which can be heard as an occasional individual click or a uniform white noise during heavy showers. Because of the very steep slope of this discharge, very high interference amplitudes are generated in the resonant ranges of the antenna. Although the capacitance of a single raindrop is only a few pF and is rapidly discharged, the high potential and large repetition frequency produce a considerable energy density, as indicated in **fig. 1F.** The effect is especially prevalent on the antennas of aircraft flying through cloud formations. A similar effect can be produced by sand or dust storms.

Pulses from radar transmitters that operate in the GHz range (as well as lower frequency over-the-horizon radars) are another source of noise. These transmitters use relatively short pulses (**fig. 1G**) and, depending on the shape of the keying waveform modulation, generate sidebands with various frequency (amplitude) spectra. Similar to the case of baseband pulses, the spectral line spacing of rf pulses is determined by the repetition frequency. Zero spectrum points occur at the reciprocal of the pulse length and its multiples.

effects of pulses on narrow-band systems

A narrow-band system with tuned (resonant circuit) amplifiers only enhances frequency components that fall within its passband. An individual resonant circuit is "shock"-excited to oscillation at its resonant frequency by an impulse slope. The transient duration is dependent on the bandwidth, as determined by the circuit Q. In the case of multistage amplifiers or multipole filters, the output pulse delay is dependent on the circuit group delay, t_g. This increases linearly with the number of resonators and is generally measured from the input impulse time, t_o to the time at which the output signal has risen to 50 percent of its peak amplitude. An approximate formula gives $t_g = 0.35N/\Delta f$, where N is the number of resonant circuits, Δf is the bandwidth (Hz) and $t_r = 1/\Delta f$. If different bandwidth stages are cascaded, rise time is determined mainly by the narrowest filter. The group delay results from the

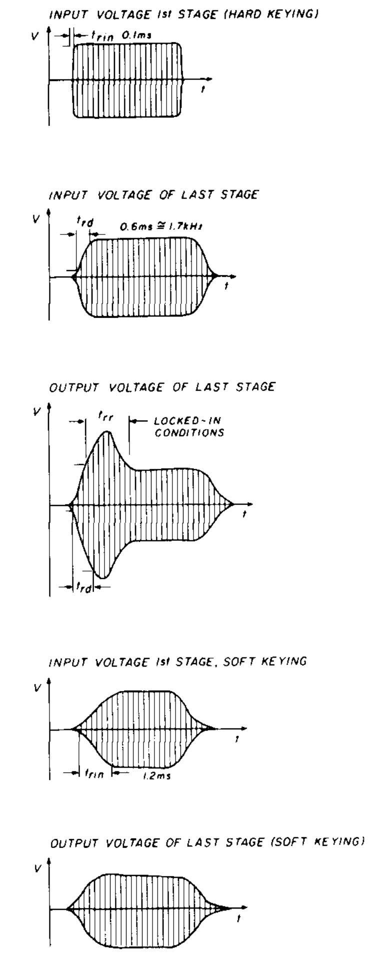

fig. 2. Impulse drive of an rf amplifier with AGC. (Courtesy of M. Martin and *VHF Communications*, Spring, 1980.)

sum of the individual delay times.

If short rise time rf impulses are fed to an amplifier that has a much longer rise time, three different types of responses can occur.[8]

- If the input pulse has duration, t_p, longer than the transient time t_{rv}, the output signal achieves the full amplitude and maintains it for the duration of the drive time less the transient time $t_p - t_{rv}$.
- If t_p is equal to t_{rv}, the output signal achieves full amplitude during time t_{rv}, but then immediately starts to decay to zero in a period, t_{rv}.
- If the pulse is shorter than the circuit transient time, the response is essentially that of the transient, but with an amplitude which only reaches a portion of the pulse; i.e., the shorter the pulse, the smaller the amplitude produced by the amplifier. In other words, a substantial portion of the spectrum of the input pulse is not within the bandwidth of the amplifier, and, therefore, does not contribute to the output amplitude.

In many systems an AGC circuit is provided to ensure that a large range of input signal voltages is brought to the same level at the demodulator output. The AGC control voltage is generated subsequent to the narrow-band i-f filter. This filter might have a bandwidth of from approximately 2 to 12 kHz, corresponding to transient times of about 0.2 to 1 millisecond. Earlier stages have much broader bandwidths. This means that steep input pulses can drive earlier amplifier stages into saturation before a reduction in gain is effected by AGC (whose response time is generally longer than the narrow band filter transient response). This is especially true in superheterodyne receivers, where selectivity is determined in the final i-f, often after substantial amplification of the input signal. Thus, the audible interference amplitudes may be several times stronger than the required signal level after the AGC becomes effective. A long AGC time constant worsens the situation. It is only when the rise time of the input pulse is longer than the AGC response time (e.g., during telegraphy with "soft" keying) that the output amplitude will not overshoot, as shown in **fig. 2.**

An effective method of limiting the maximum demodulator drive, and thus reducing the output pulse peak, is to clip the signal just in front of the demodulator with symmetrically limiting diodes, so that the i-f driver amplifier is not able to provide more than the limited output level — e.g., 0.7 volts peak-to-peak. It is necessary in this case that the AGC detector diode be delayed no more than a fraction of this level (corresponding to 0.4 volts) so that the clipping process does not interfere with AGC voltage generation. Use of a separate AGC amplifier, not affected by the limiter, will also assure this, and can provide an amplified AGC system to produce a flatter AGC curve.

methods for suppressing interfering pulses

Three different methods are used to suppress interfering pulses:[9]

- *Balancers* attempt to reproduce the pulse shape without the signal in a separate channel, and then perform a subtraction from the channel containing both signal and pulse.
- *Limiters* attempt to prevent the pulse level from becoming excessive.
- *Blankers, or silencers,* attempt to detect the onset of a pulse, and reduce to zero the gain of the signal amplifier chain, at an early stage, for the duration of the pulse.

Balancer systems are designed to obtain two signals in which the signal and noise components bear a relatively different relationship to each other. The two signals are connected in opposition so as to eliminate the noise while keeping the signal. The main problems with this type of impulse noise suppression are obtaining suitable channels and exactly balancing out the noise impulse, which is generally many times stronger than the desired signal.

In commercial service, attempts have been made to use different frequency channels with identical bandwidths to get the same impulse shape, but with the signal in only one channel. The difficulties of matching channels and finding interference-free channels makes this approach unsatisfactory in most cases. Other approaches have attempted to slice the center from the pulse (to eliminate the signal) or to use a high-pass filter to pass only the higher frequency components of the pulse for cancellation. While some degree of success can be achieved with such circuits, they generally require very careful balancing and hence are not useful when a variety of impulses and circuit instabilities are encountered.

This type of circuit can be useful where the impulse source is a local one which is physically unchanging. In this case, a separate channel from the normal antenna can be used to pick up the pulse source with negligible signal component, and the gain of the pulse channel can be balanced carefully using stable circuits (and a feedback gain control channel if necessary). It has also been reported that modern adaptive antenna systems with sufficiently short response times can substantially reduce impulse noise coming from directions other than the signal direction.

Since most of the noise terms contain relatively large peaks, limiters have been used, especially in a-m reception (which includes, of course, telegraph through full-carrier voice signals) to clip audio signal peaks which exceed a preset level. **Figure 3** shows a series limiter circuit at the output of an envelope demodulator which has proven effective in reducing

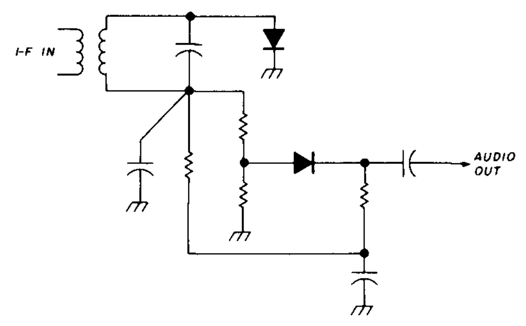

fig. 3. Schematic diagram of automatic series noise limiter circuit.

audio noise caused by impulse interference. This type of circuit makes listening to the signal less tiring, but does not improve intelligibility of the received signal. The limiting level may be set to a selected percentage of modulation by adjusting the tap position of the two resistors feeding the limiter diode's collector. If set below 100 percent, the limiting level also limits peaks of modulation. Since these seldom occur, such a setting is acceptable.

Because the impulse amplitude is higher and the duration shorter in the early stages of a receiver, limiting in such stages reduces the noise energy with less effect upon signal than limiting in later stages. Some fm receivers use i-f stages which are designed to limit individually, while gradually reducing bandwidth by cascading resonant circuits. Such a design eliminates strong short impulses early in the receiver, before they have had a chance to be broadened by the later circuits. Such receivers perform better under impulse noise conditions than those which introduce a multipole filter early in the amplifier chain. However, wideband limiting can reduce performance in the presence of strong adjacent channel signals.

The principles discussed are also applicable to data receivers. While the impulse interference is stronger than the signal, the signal modulation contributes little to the output. Generally, the data symbol duration is longer than the duration of the input impulses. If the impulse can be reduced or eliminated before the establishment of final selectivity, only a small portion of the signal interval is distorted, and a correct decision is much more likely. Consequently, limiters at wide bandwidth locations in the amplifying chain can result in considerable reduction of error rate in a data channel. Again, the possibility of interference from adjacent or other nearby channel receivers must be considered.

Impulse noise blankers are based on the principle of "opposite modulation." In effect, a stage in the signal path is modulated so that the signal path is blanked by an amplitude modulation process for the duration of the interference. It is also possible to use a frequency modulation method in which the signal path is shifted to a different frequency range. This latter procedure[10] uses the attenuation overlap response of i-f filters in a double superheterodyne. The second oscillator is swept several kHz from nominal frequency for the duration of the interference so that the gain is reduced to the value of the ultimate selectivity in accordance with the slope of the filter curves. This method is especially useful since the switching spikes which often accompany on-off modulation should not be noticeable. However, when using an fm modulator having high speed (wide bandwidth), components can appear within the second i-f bandwidth from the modulation. The most stringent limitation of this method is the requirement for two identical narrowband filters at different frequencies along with an intermediate mixer. This technique is limited to a double conversion superheterodyne with variable frequency first (local) oscillator.

When using an amplitude modulation method, two types of processing are possible:

(A)The interference signal is tapped off in parallel at the input of the system and increased to the trigger level of a blanker by an interference channel amplifier having a pass bandwidth which is far different

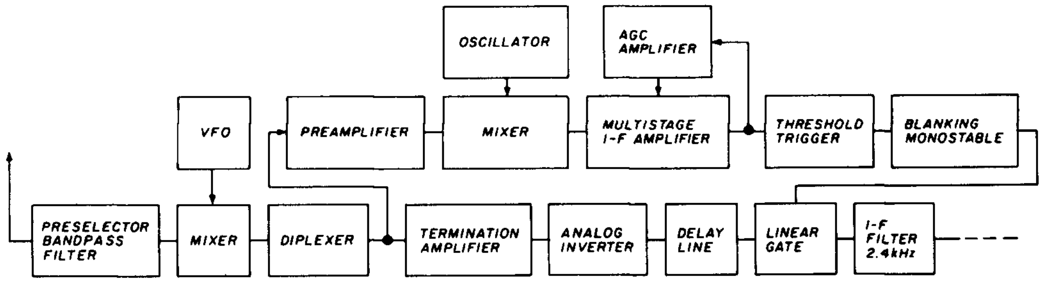

fig. 4. Block diagram of superheterodyne with noise blanker.

from the signal path. This method is effective only against very wideband interference, since noticeable interference energy components must fall into the passband range to cause triggering. This method will not be effective in the case of narrow-band interference, such as radar pulses, which are within or directly adjacent to the frequency range to be received.

(B)The interfering signal is tapped off from the required signal channel from the mixer and fed to a fixed-frequency, second i-f amplifier, where it is amplified up to the triggering level.[2,3] Since there is danger of crosstalk from the interference channel to the signal amplifier channel, it is advisable to have a frequency converter stage in the interference channel. This would process the interference at a different frequency than the signal i-f. In using this method, make sure that no switching spikes generated during the blanking process are fed back to the interference channel tap-off point. If they are, there will be danger of pulse feedback. The return attenuation must, therefore, exceed the gain in the interference channel between the tapping point and the blanker.

The blanker must be placed ahead of the narrowest i-f filter in the signal path. It must provide blanking action before the larger components of the transient have passed this filter. Therefore, we must assure a small group delay in the interference channel by use of a sufficiently broad bandwidth and a minimum of resonant circuits. It is desirable to insert a delay between the tap-off point and the signal path blanker so that there is sufficient time for processing the interference signal. If this is done, it is not necessary to make the interference channel excessively wide, while still assuring the suppression of the residual peak.

Figure 4 is the block diagram of a superheterodyne that uses this type of impulse noise blanker. **Figure 5** illustrates its operation in the presence of a strong interfering radar pulse. An essential part of the blanker is the use of a gate circuit that can operate linearly over a wide dynamic range. **Figure 6** shows such a gate, using multiple diodes. The circuit is driven by a monostable flip-flop which is triggered by the noise channel. **Figure 7** is a schematic of a noise blanker circuit designed along these lines. When the noise channel is wider than the signal channel, this type of noise reducer can also have problems from interfering signals in the adjacent channels.

squelch circuits

Sensitive receivers produce considerable noise voltage output in the absence of a signal. This condition can occur when tuning between channels or when the station being monitored has intermittent transmissions. At the audio output the noise can be annoying and, if repeated frequently, fatiguing. To reduce this problem, circuits are often provided to reduce the output when a signal is not present. These circuits have been referred to as *squelch, muting,* and *quiet AVC (QAVC) systems.* The choice of which circuit to use depends on the received signal characteristics.

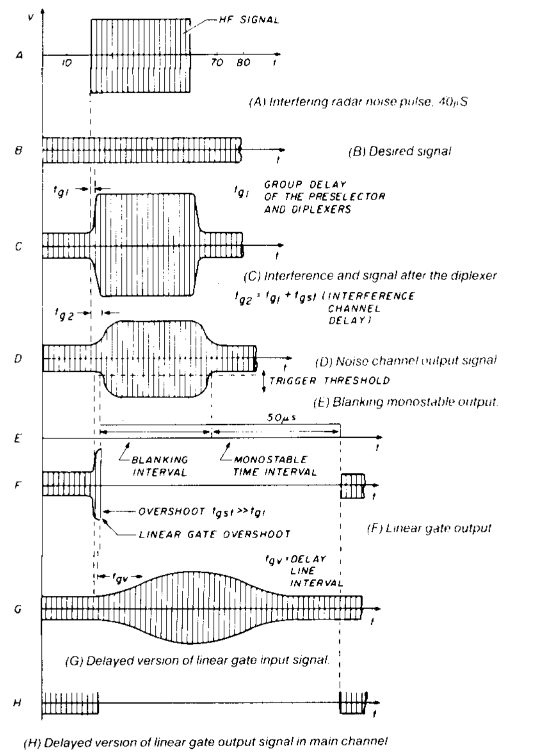

fig. 5. Observed signal waveforms in a superheterodyne receiver that uses an impulse noise blanker.

Squelch circuits for a-m receivers generally operate from the AGC control voltage. When a weak signal or no signal is present, the voltage on the AGC line is at its minimum and receiver gain is maximum. When a usable signal is present, the AGC control voltage rises to reduce the receiver gain. The voltage variation tends to rise approximately logarithmically with increasing signal levels. By using a preset signal level threshold, it is possible to gate off the audio output signal whenever the signal level drops below this point. Such a system can be used to mute the receiver during the tuning process. The threshold may also be set for the level of a particular signal with intermittent transmissions, so that noise or weaker interfering signals are not heard when the desired signal is off. When the transmission medium causes signal fading, as is common at hf, squelch circuits are somewhat less effective for this use because the threshold must be set low enough to avoid squelching the desired signal during its fades. This provides a smaller margin to protect against noise or weaker interfering signals.

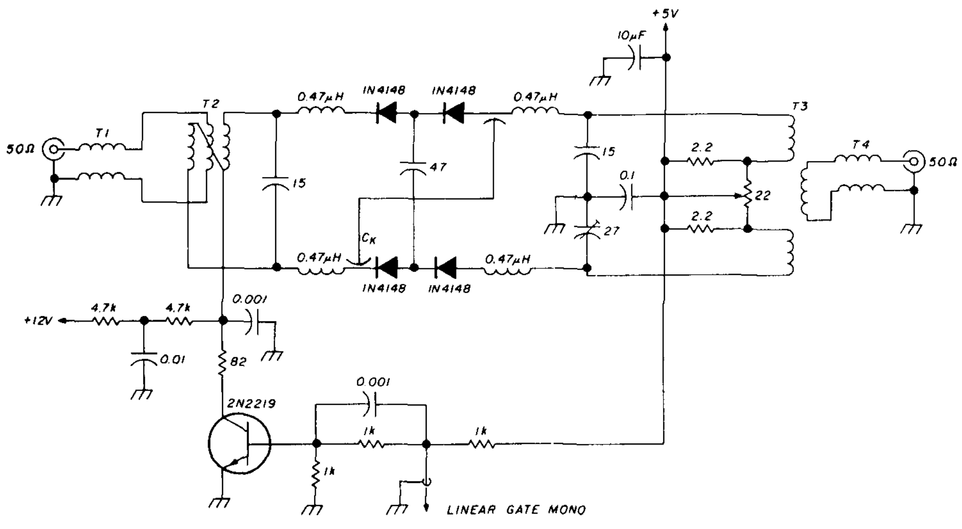

fig. 6. Schematic diagram of blanker gate with high dynamic range.

A typical a-m squelch system is illustrated in **figs. 8** and **9**, where a diode gate is used to reduce the output signal. Many types of switches have been used for this purpose, including biasing the demodulator diode and biasing one element of a multi-element amplifying device. The latter approach was frequently used with receivers that employed multigrid vacuum tube amplifiers. However, it can be applied to multigate FET amplifiers or balanced amplifier ICs with current supplied by a transistor connected to the common base circuit of the amplifying transistor pair. **Figure 10** shows these alternate gating techniques.

Many fm receivers do not use AGC circuits, but depend on circuit limiting to maintain the output level constant from the demodulator. In this case, squelch may be controlled by the variations in voltage or current which occur in the limiter circuits. Such changes occur when single-ended amplifiers are used for limiting, but may not be so readily available in balanced limiter arrangements. Furthermore, the wide range of threshold control provided by AGC systems is generally not available in limiters. This tends to make fm squelch systems, which are dependent on the signal level, more susceptible to aging and power supply instabilities than AGC operated systems. Consequently, two other types of control have evolved for fm use: noise-operated and tone-operated. (The latter could be used for a-m, also.)

Figure 11 is a block diagram of a noise-operated squelch. This system makes use of the fact that output noise characteristics from a frequency demodulator change when no signal is present. At the low output frequencies, when noise alone is present in the fm demodulator, there is a high noise level output, comparable to that at other frequencies in the audio band. As the strength of the (unmodulated) signal rises, the noise at low frequencies decreases, while the noise at higher frequencies decreases much less rapidly.

If in **fig. 11**, the squelch low-pass filter cuts off at, say, 150 Hz, it will be uninfluenced by modulation components. If the gain of the squelch amplifier is set so that the squelch rectifier produces 5 volts when S/N = 0, then a 7-dB signal level will cause this output to drop to about 0.03 volts. A threshold may readily be set to cause the squelch gate to open at any S/N level between − 3 dB and 7 dB. Because the control voltage level is dependent on the gain of the rf, i-f, and squelch amplifiers, variations in squelch threshold may occur as a result of gain variation with tuning or because of gain instabilities. If a second filter channel (**fig. 12**) tuned above the baseband is used, the two voltages can be compared to key the gate on. While both are subject to gain variations, their ratio is not. Better threshold stability results. A similar technique has been proposed for SSB voice, where noise density is uniform, but modulation energy is greater below 1 kHz.

With the difference approach, the range of threshold control is, however, limited. A weak interfering signal which would produce negligible interference with the desired signal may still operate the squelch gate. Tone-operated squelch was devised to overcome this problem. A small-deviation, low-frequency tone (lower than the modulation frequencies) is added to the transmitted signal. At the receiver, a narrow-band filter is tuned to the tone, and its output is amplified and rectified to operate a trigger for the squelch gate.

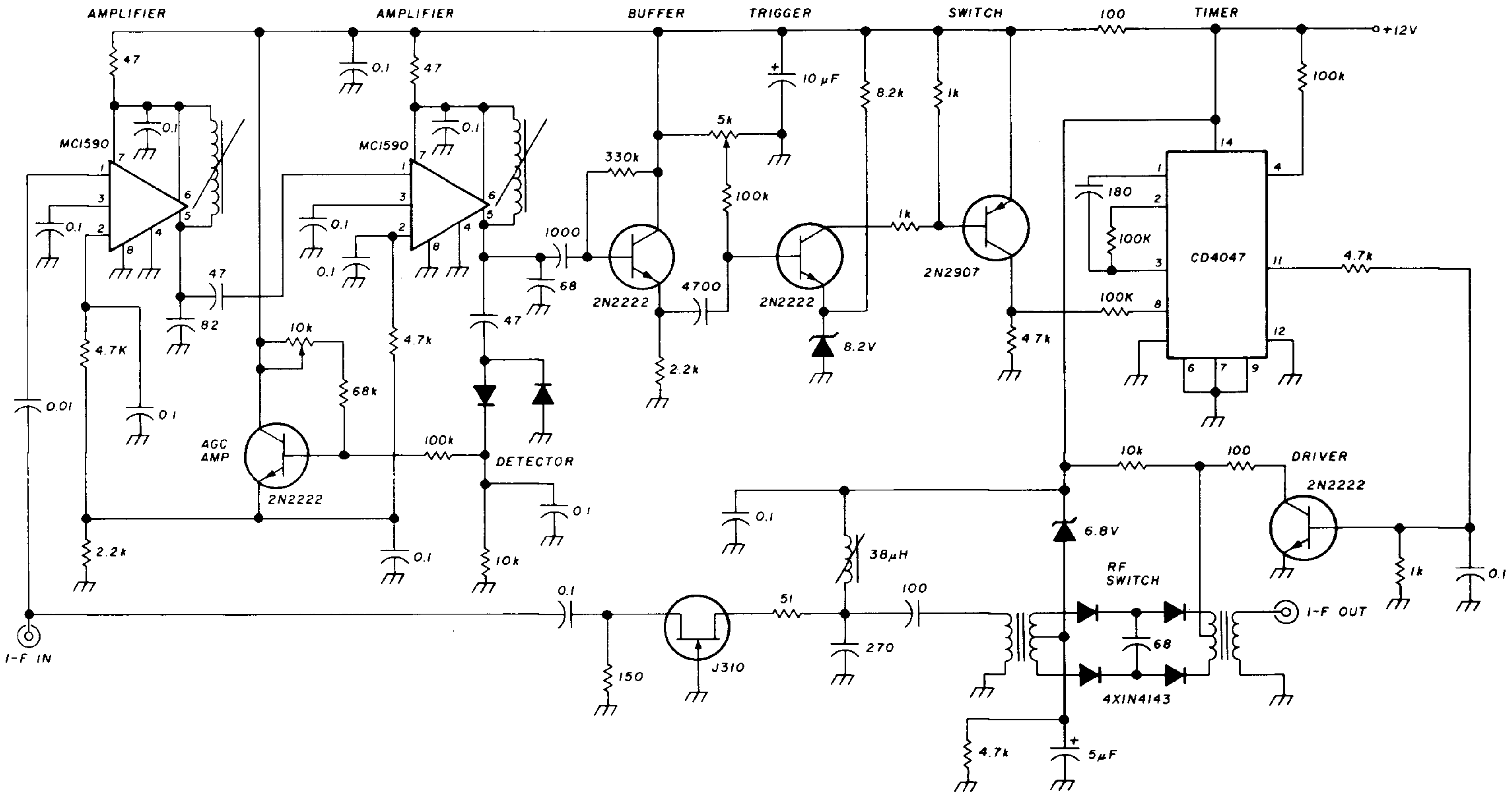

fig. 7. Schematic diagram of noise blanker circuit.

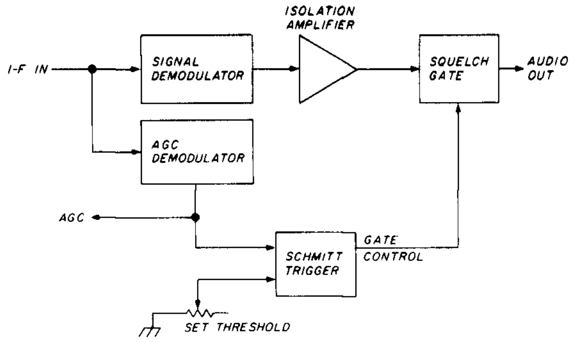

fig. 8. Block diagram of a-m squelch circuit.

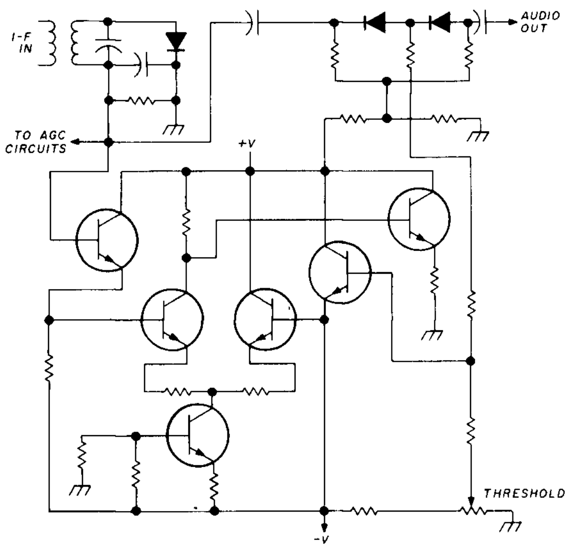

fig. 9. Schematic diagram of a-m squelch circuit.

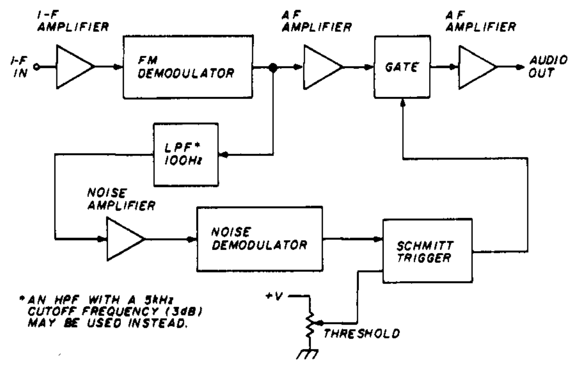

fig. 11. Block diagram of noise-operated squelch circuit for fm receiver.

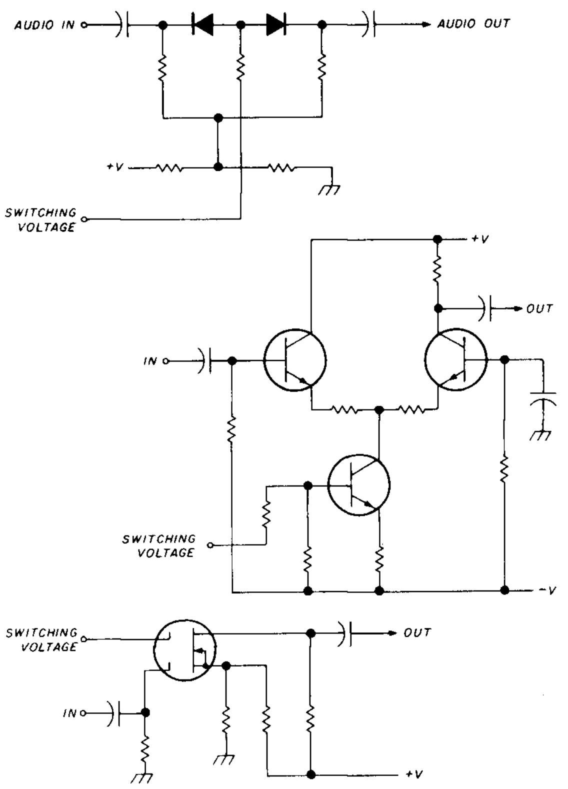

fig. 10. Some gate circuits for squelch application.

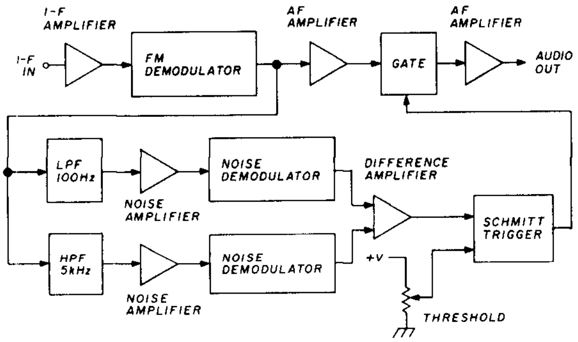

fig. 12. Block diagram of improved noise-operated squelch circuit for fm.

However, in some commercial communication systems, with multi-user net operation on one frequency, a coding scheme known as selective call (SelCall) has been devised so that users need receive only those messages directed toward them. In this type of signaling scheme, the caller sends a multitone or digital code at the beginning of the message to indicate the identity of the called party or parties. Only if the receiver code matches the transmitted code is the output gate enabled to transmit the message to the receiver user. This type of system may be used with both analog and digital modulations, and is independent of the modulation type (a-m, fm, pm) used for transmission. This method is more elaborate than normal squelch systems, but performs an important function in multi-user nets.

conclusion

Several of the basic techniques and their circuits used to handle the introduction of noise in receiving systems have been described. While this discussion is by no means all-inclusive, it is nevertheless indicative of some of the basic approaches taken to solve this problem.

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