Comm Links

Spurious Transmitter Outputs

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When a radio transmitter is operated legally, the user is expected to transmit only on the assigned frequency, and none other. Ideally, when a transmitter produces a radio-frequency (RF) signal, only that frequency is created. Likewise, when the "ideal-but-never-achieved" signal is modulated, the only new signals that are generated are those created by the modulation sidebands. But, in the real world, things never seem to gravitate toward the ideal—things can, and usually do, get a bit nastier. Let's take a look at some of the different forms of output signal normally emanating from a transmitter.

Figure 1 shows an amplitude-vs-frequency plot of a hypothetical transmitter, as displayed by a *spectrum analyzer* (*i.e.*, a frequency swept receiver with its output connected to an oscilloscope that is swept with the same sawtooth as the receiver's local oscillator).

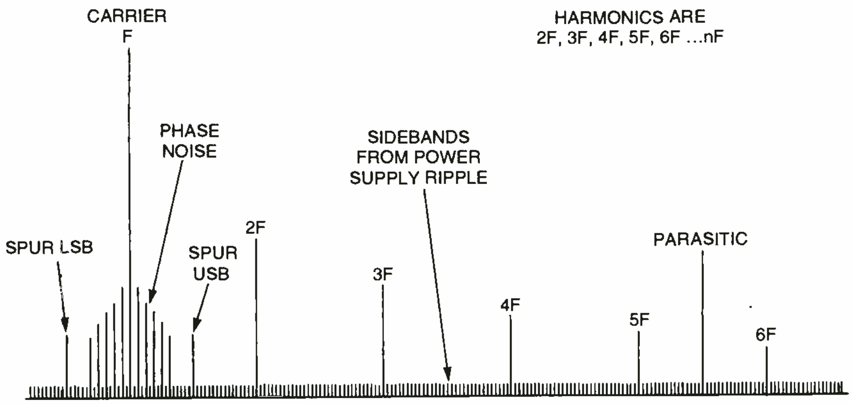

Fig. 1. Shown here is an amplitude-vs-frequency plot of a hypothetical transmitter, as displayed by a spectrum analyzer.

The main signal is the carrier, F, which is the highest amplitude "spike" in the display. We'll consider only an unkeyed continuous wave signal because modulation sidebands would make a mess out of our clean little picture. All of the amplitudes in Fig. 1 are normally measured in dBc (decibels below the carrier). A signal that is −3 dBc, for example, would be 3 dB lower than the carrier or about half the power of the carrier. For spurious outputs, the lower the level the better, so look for high negative dBc values (*e.g.*, −60 dBc or more).

DIRECT INSTABILITY

If both the input and output ends of an RF amplifier are tuned (often the case) or there is unexpected coupling between input and output, causing feedback of the output signal, then the amplifier may oscillate on either the transmitter's operating frequency or on a nearby frequency. If the transmitter's "on-frequency" output level does not drop to zero when the drive signal is reduced to zero, then suspect direct instability as a cause of the oscillation. That's especially likely if the input and output are tuned to the same frequency, giving rise to what used to be called "tuned-grid-tuned-plate (TGTP) oscillations."

PHASE NOISE

Because the process of generating a single frequency (F) is not a perfect and precise operation—there's normally a certain amount of noise energy surrounding the carrier. Some of the signals are caused by thermal noise in the circuit, as well as other sources. The signals tend to modulate the carrier, creating the phase-noise sidebands shown in Fig. 1.

HARMONICS

Any complex waveform can be represented by a series of sine and cosine waves that make up its *Fourier series* or *Fourier spectrum*. If a transmitter produces a pure sinewave output signal, then only the carrier frequency (F) appears in the spectrum. But if the signal is distorted in any way, no matter how slightly, harmonics appear. Those signal components are integer multiples of the harmonic and so they manifest themselves at 2F, 3F, 4F . . . nF. For example, a 780-kHz, AM broadcast-band transmitter can generate harmonics at 1560 kHz, 2340 kHz, 3120 kHz, 3900 kHz, and so forth. The specific harmonics and their relative amplitude differ from case to case, depending on the circuit and the cause of the distortion.

Like all spurious emissions, the harmonics must be suppressed so that they do not interfere with some other services.

VHF/UHF PARASITICS

A transmitter can be designed to operate at a relatively low frequency (in the medium-wave or high-frequency bands), but in operation produce large output signals in the VHF or UHF bands. The problem is caused by stray capacitances and inductances in the circuit. Although the problem can manifest itself in transistor-based RF-power amplifiers, it is most commonly associated with vacuum-tube-based RF amplifiers. Unfortunately, the really high-power amplifiers used in today's broadcast transmitters are vacuum-tube based . . . making the problem even more pronounced due to the power levels involved.

Barkhausen's criteria for oscillation are: 1) a phase shift of 360 degrees at the frequency of oscillation, and 2) a loop gain of one or more at that frequency. If the phase inversion of the amplifier plus the frequency selective phase shifts caused by the stray capacitances and inductances (including those inside components) add up to 360 degrees at any frequency where there is gain, then oscillation takes place. Because strays are typically small, the oscillating frequency tends to be in the VHF and higher-frequency ranges of the radio spectrum.

POWER-SUPPLY RIPPLE

Like most electronic devices, transmitters are powered by direct current (DC), while the utility company supplies alternating current (AC) at a frequency of 60 Hz (some countries use 50 Hz). Therefore, the AC voltage must be fed through a converter circuit (DC power supply) that produces an impure form of DC called pulsating DC. That form of DC, which is produced at the output of the rectifier, contains a ripple-factor impurity at a frequency equal to the AC line frequency (60 Hz) in half-wave rectifiers or twice the AC line frequency (120 Hz) for full-wave rectifiers. The ripple factor represents a small amplitude variation that tends to amplitude modulate the carrier. That produces a low-level "comb" spectrum with RF signals spaced every 120 Hz up and down the band.

Normally, that power supply by-product isn't a problem; but if the DC power-supply ripple filtering is ineffective or if the application is particularly sensitive, then it'll be heard. In some cases, such as the 400-Hz power supplies used in aircraft systems or transmitters that use 5- to 100-kHz switching power supplies, the problem can be much more pronounced.

LOW-FREQUENCY SPURS

When an amplifier is misadjusted or when an RF feedback path exists through the DC power supply (or other circuits), then there is a strong possibility of the amplifier oscillating at a low frequency (perhaps audio or below). The oscillations amplitude modulate the RF signal, giving rise to spurious emissions. I've seen solid-state VHF RF power amplifiers break into low-frequency oscillation when either mistuned or incorrectly biased. If the low-frequency oscillation is caused by DC power-supply coupling, then both a high-value electrolytic and low-value ceramic-disc (or similar) capacitor can be used in parallel for decoupling.

One peculiar form of low-frequency oscillation occurs in supposedly broadband solid-state power amplifiers. In some units, a broadband toroid transformer is used to couple the input and output to the transistors of the power amplifier. In such circuits, a DC blocking capacitor is used to prevent bias from being shorted out through the transformer. Unfortunately, the inductance of the transformer and the capacitance of the coupling capacitor form a tuned resonant circuit. If both input and output are tuned to the same frequency, then a species of TGTP-like oscillations are produced. Such oscillations tend to occur in the 10- to 200-kHz range, generating spurious RF sidebands (SPUR LSB and USB in Fig. 1) spaced at that frequency from the carrier, F.

FREQUENCY HALVING

Solid-state, bipolar-transistor, RF-power amplifiers sometimes show an odd spurious emission in which a signal is produced at half of the carrier frequency. That phenomenon is evident when the input and output load and/or tuning conditions are such that the transistor's operating parameters vary over cyclic excursions of the signal. Unfortunately, that effect is seen in non-linear situations, so odd multiples of the halving frequency occur. Suspect that to be the problem when a spurious emission occurs at 1.5F because it could be the third-harmonic of a halving situation.

AUDIO (AND OTHER) STAGE OSCILLATION

Few transmitters produce a single frequency with no modulation, so Fig. 1 is rather simplistic in order to illustrate the actual case. When the transmitter is modulated (AM, PM, FM *etc.*), sidebands appear. Let's consider only the AM case for simplicity's sake. Let's say we have a 1-kHz audio-sinewave tone modulating a 1000-kHz (1-MHz) RF carrier. When the modulation oc-curs, a new set of sideband signals appear: The lower sideband (LSB) will appear at 1000 kHz − 1 kHz = 999 kHz, while the upper sideband (USB) will appear at 1000 kHz + 1 kHz = 1001 kHz. In the case of a voice amplifier, the nominal range of audio frequencies is about 300 Hz to 3 kHz, so the normal speech sidebands will appear at ±3 kHz from the carrier, or in our 1000-kHz case, from 997 kHz to 1003 kHz.

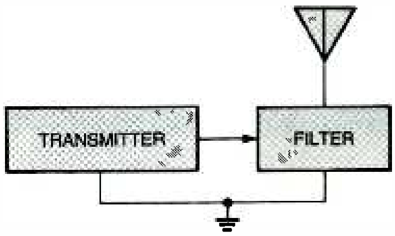

Fig. 2. In order to prevent their rigs from interfering with other RF services (particularly those in the VHF/UHF bands, especially TV channels), ham operators place filters in series with the outputs of their HF transmitters.

But what happens if the audio stages oscillate at a frequency higher than the audio range? The LSB/USB pairs appear at those frequencies as well. I can recall a VHF FM transmitter, used in the 2-meter amateur radio band (144-148 MHz), that produced signals every 260 kHz up and down the band from the transmitter's nominal output frequency. The cause turned out to be "ultrasonic" oscillation of the FM reactance modulator stage. The manufacturer supplied a retrofit kit that provided better decoupling (capacitors and ferrite beads) and grounding of the circuit. Once the oscillation ceased, the RF output was cleaned up.

Keep Barkhausen's criteria for oscillation in mind: Any time there is a frequency at which the loop gain is greater than unity and the overall phase shift is 360 degrees, there will be oscillation. That's true regardless of whether the sub-assembly is an audio amplifier, reactance modulator, or RF stage.

WHAT TO DO?

There are three basic strategies to reducing emissions to the level required by the Federal Communications Commission: 1) adjust (or repair) the transmitter correctly, 2) use shielding, and 3) filter the output of the transmitter.

The adjustment issue should go without saying, but apparently it is a problem. One trick that many transmitter operators pull is to either increase the drive to a final RF power amplifier to increase the output power or peak the tuning for maximum output. That isn't always the smartest thing to do. Never operate the transmitter at levels above the manufacturer's recommendations. There are cases where tuning up the amplifier using a spectrum analyzer as well as an RF power meter will

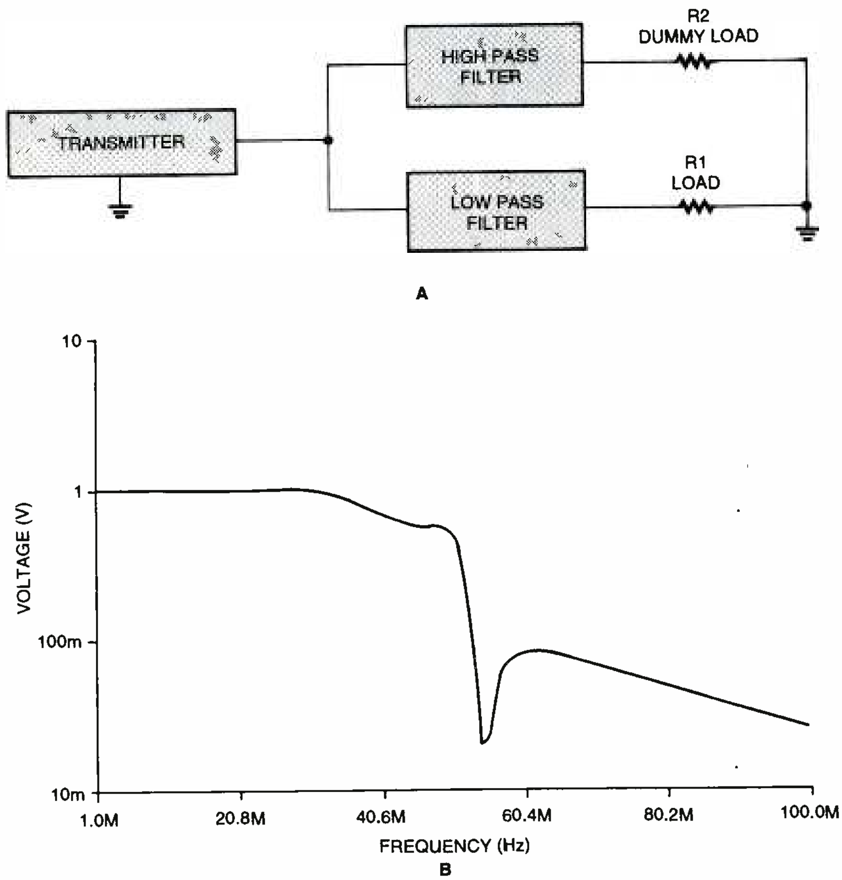

Fig. 3. One of the best approaches to filtering is to use an absorptive filter (shown in A), which is comprised of two separate filters—one high-pass and one low-pass—with the same cut-off frequency. In one variation of that configuration, a 40-MHz absorptive filter coupled to a 56-MHz notch filter produced the frequency response shown in B.

show that the increased power level apparent on the meter is due to the production of harmonics or other spurs and not the carrier.

At one time, it was relatively common to see illegal operation of citizens-band (CB) transmitters. In the tube days, it was relatively easy to increase the RF-output power from 4 watts, on average, to about 8 watts. Consider this situation: A 2:1 increase is only 3 dB, which is about half an S-unit on a distant receiver . . . or about half as much as the minimum discernible change. Yet, operating the transmitter that way not only doesn't produce the desired end result, it creates a distinct possibility of high harmonic or other spurious emissions!

When repairing a transmitter, use only parts that are recommended. That's especially true of capacitors and semiconductors. All capacitors exhibit a bit of stray inductance, as well as capacitance, and so they'll have a self-resonant frequency. If that frequency meets Barkhausen's rules, then oscillation will occur. In general, the problem comes from using a cheaper capacitor, or different type of capacitor, from the one used originally. Also, be very wary of *replacement transistors* that are *not* really and truly "exact" replacements. Such components frequently cause either UHF or low-frequency oscillations.

Shielding is an absolute *must* in transmitters, especially higher-power transmitters. Even low-power transmitters can cause sufficient spurious-emission levels so as to interfere with other services. Transmitters operated outside their cases, or with critical shields removed, are candidates for high radiation of spurs.

Even small shields are important. I recall one transmitter that had a large amount of AM splatter, and a very broad signal, as well as output components appearing up and down the band. The rig was a 300-watt AM HF band transmitter. The thing looked normal, but a photo of the transmitter in a service manual revealed a missing bit of metal on the master oscillator's shielded housing. Someone had removed that little bit of sheet metal and allowed a slot to appear that admitted RF from the final into the oscillator housing. That feedback path proved critical. Restoring the shielding fixed the problem.

FILTERING

Ham operators use low-pass filters in the outputs of their HF transmitters in the transmission line to the antenna to protect VHF/UHF bands (especially TV channels), as shown in Fig. 2. In other cases, a high-pass filter or band-pass filter may be used, depending on the frequencies that need protecting.

One of the best approaches to filtering is to use an absorptive filter as shown in Fig. 3A. The absorptive filter is comprised of two separate filters—one high-pass and one low-pass—with the same cut-off frequency. Either filter can be used for the output, depending on the case. Let's consider a ham-radio situation wherein the VHF band TV channels must be protected from the high-frequency emissions of the transmitter. In that case, as shown in Fig. 3A, the low-pass filter is used to feed the load (R1, which can be an antenna), and the high-pass filter feeds a non-radiating dummy load. The harmonics and parasitics, therefore, are absorbed in the dummy load, while the desired signal is output to the load.

In other cases, where the protected frequencies are below the transmitter frequency, then the roles of the high-pass and low-pass filters are reversed—R2 becomes the load and R1 becomes the dummy load.

Some absorptive filters also place a wavetrap across the load in order to protect specific frequencies. In one version, there is a 40-MHz absorptive filter with a 56-MHz notch filter (*i.e.*, a series-tuned LC circuit across the load). The design was published in *The ARRL RFI Book* for ham transmitters. I modeled the circuit on *Electronics Workbench* and produced the frequency response shown in Fig. 3B. Note that the gain of the filter drops off starting just before 40 MHz (which is the −3 dB point), and there is a deep notch at the 56-MHz point. The design

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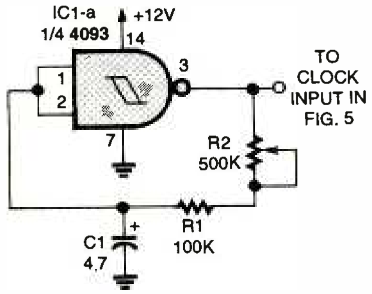

Fig. 7. Timing accuracy can be increased by replacing the electromechanically derived clock signal of the circuit in Fig. 4 with this simple variable-frequency oscillator.

PARTS LIST FOR THE ELECTRONIC TIMING CIRCUIT (FIG. 7)

IC1—4093 CMOS quad 2-input NAND Schmitt trigger, integrated circuit
R1—100,000-ohm, ¼-watt, 5% resistor
R2—500,000-ohm potentiometer
C1—4.7-µF, 25-WVDC, electrolytic capacitor

tion output in Fig. 4 remains high for one-half turn of the flywheel, the ignition-trigger pulse occurs at the very beginning of the output pulse.

EXHAUST-CONTROL CIRCUIT

A circuit to control the engine's exhaust valve is shown in Fig. 6. When the exhaust output of the circuit in Fig. 4 goes positive, the HexFET (Q1) in Fig. 6 turns on, pulling in the solenoid and opening the exhaust valve for one-half turn of the flywheel. The difficulty in getting the exhaust system to operate properly is most likely to be encountered in setting up the mechanical linkage between the solenoid and the valve, so use care.

ELECTRONIC TIMING

Sometimes getting everything in an electro-mechanical combination to function as planned can be a frustrating experience. The simple auto-run circuit shown in Fig. 7 can be used to ease that problem. The interface portion of the circuit shown in Fig. 4 can be replaced by or modified to match the auto-run circuit—in essence, a free-running, variable-frequency oscillator—shown in Fig. 7. The oscillator circuit can be connected in place of R1, IC1-a, C1, and S1 of Fig. 4, eliminating the that circuit's dependence on an electromechanical timing system.

AN ALTERNATE IGNITION/EXHAUST CONTROLLER

Another method of controlling the engine's ignition and exhaust valve is shown in Fig. 8. In that circuit, a 4017 divide-by-ten counter—which has ten decoded outputs that sequentially go high—replaces the 4027 JK flip-flop used in the Fig. 4 circuit. Note that the input interface portion of the circuit shown in Fig. 8 is the same as that shown in Fig. 4. Because of the 4017 architecture, its output advances one count for each positive-going clock pulse.

The first count, which occurs during the compression stroke, generates a positive pulse at pin 3 of IC1-a that is applied to the clock input of IC2 at pin 14, causing IC2's pin 3 output (which is not used in this application) to go high. The next positive-going input from the interface circuit causes IC2 to advance one count, which causes pin 3 to return to a low state and pin 2 (the next one of IC2's sequential outputs) to go high, triggering the spark-generating circuit. The next count causes pin 4 of IC2 to go high, actuating the exhaust solenoid.

PARTS LIST FOR THE ALTERNATE IGNITION/ EXHAUST CONTROLLER (FIG. 8)

SEMICONDUCTORS

IC1—4093 CMOS quad 2-input NAND Schmitt trigger, integrated circuit
IC2—4017 CMOS decade counter/divider, integrated circuit

ADDITIONAL PARTS AND MATERIALS

R1—100,000-ohm, ¼-watt, 5% resistor
C1, C2—0.1-µF, ceramic-disc capacitor
S1—Magnetic reed switch (see text)

Using the 4017 in Fig. 8, as opposed to the 4027-based circuit in Fig. 4, requires fewer parts to do the same job. How many more methods can be used to accomplish the same task? Who knows, but the more ways we try to solve a problem the better prepared we'll be to solve future problems. What a dull world it would be if we all sang from the same book.

I know most of you will not run out and buy an old air compressor and turn it into a running antique, but I hope that you can use one of these circuits in a future project. ■

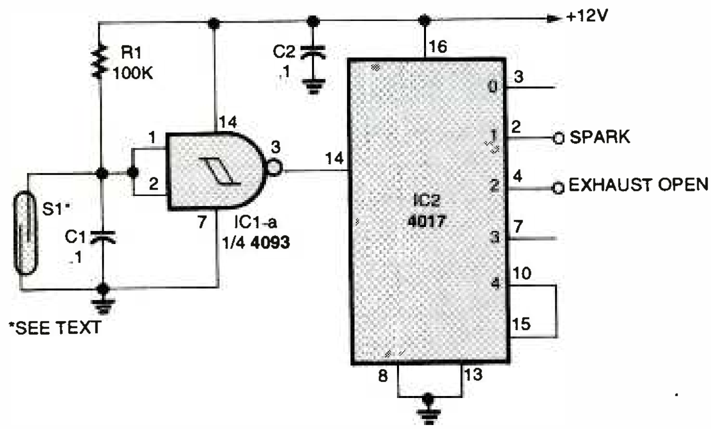

Fig. 8. Shown here is another method by which the engine's ignition and exhaust functions can be controlled. This circuit, while needing fewer components when compared to the Fig. 4 circuit, provides similar outputs to those of that circuit and can be used in conjunction with the previously discussed add-on circuits.

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appears to be successful. In some cases, such as VHF or UHF communications systems, the series-tuned LC network might be replaced with a cavity-tuned filter.

Well that's about all the space that's allotted to our discussion for this month, but be sure to join us next time around. Until then keep in touch. I can be reached by snail mail at PO Box 1099, Falls Church, VA, 22041, or by e-mail at *carrjj@aol.com.* ■