# Power MOSFET "Squegging": Cause and Cure

**By Andre Adrian**

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### Introduction

Today power MOSFETs are used at Megahertz frequencies in soft switching DC-DC converters. More and more, engineers build switched-mode devices that are in fact radio frequency (RF) power amplifiers. One of the lesser known phenomena in the wondrous world of high frequency electronics is "squegging." The *Dictionary of Engineering* defines a squegging or self-quenching oscillator as "An oscillator which stops operating for a predetermined time after completing one or more cycles. Its grid bias increases during oscillation until oscillation is stopped, then decreases until oscillation reestablished. Also called squegger or blocking oscillator." [1]. In the 1920s squegging was called "motorboating," because this describes very well the sound squegging was causing in a vacuum tube audio amplifier.

The Armstrong super-regeneration receiver from 1921 is a squegging oscillator [2], as the ARRL handbook explains: "There is a related effect called squegging, which can be loosely defined as oscillation on more than one frequency at a time, but which may also manifest itself as RF oscillation interrupted at an AF rate, as in a superregenerative detector." [3].

The squegging behavior of a circuit is in most cases a malfunction. A DC-DC converter should not shut off for several cycles [4]. An oscillator should not show intermittent operation. And the power MOSFETs in an amplifier should not draw more quiescent current than intended.

### An Experiment

The radio frequency amplifier in Figure 1 uses a traditional design. The input transformer L1/L2 matches the 50Ω line impedance to 25Ω at the gate of MOSFET Q1. The output
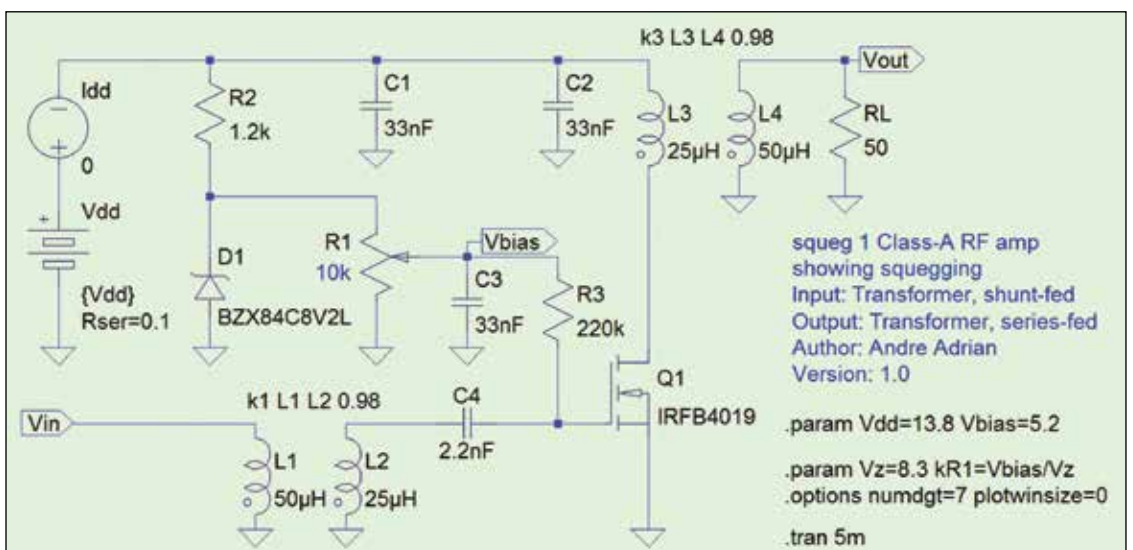


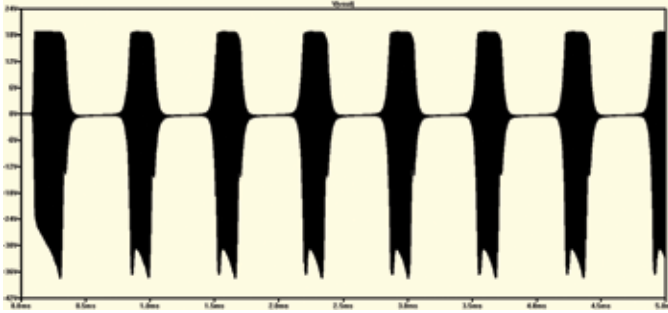**Figure 1 • Simple Class-A radio frequency amplifier.**

**Diagram 1 • Squegging class-A amplifier output voltage time curve.**

transformer L3/L4 matches again from 25Ω to 50Ω line impedance. The bias voltage is stabilized with the zener diode D1. The pot R1 allows setting the bias voltage between 0V and 8.2V. The bias voltage and the radio frequency are combined with C4 and R3. The filter capacitors C1 to C3 suppress RF voltage.

Q1, an International Rectifier MOSFET IRFB4019 advertised for class-D audio amplifier, is simulated with the Power Function Power MOSFET SPICE model that was presented by the author in *HFE's* August 2013 issue. Be aware, many other MOSFET SPICE models cannot simulate the RF behavior in detail.

To adjust the quiescent current to 300mA, we operate the amplifier without an input signal. We expect that the current rises slowly as we turn R1. But at one position of R1 the current rises dramatically. If our power supply can source enough current the MOSFET will be destroyed. What is wrong with our amplifier?

We have built a Hartley oscillator instead of an amplifier. The three feedback reactances are L2, the

MOSFET internal Miller capacity Cgd and L3. In addition, this oscillator is self-quenching. The radio frequency is amplitude modulated with an audio frequency as we can see in Diagram 1. All diagrams were created by LTSpice, a useful SPICE program from Linear Technology.

Wes Hayward says about squegging in bipolar junction transistor (BJT) oscillators: "It can occur when the starting gain is high and the series capacitor in the feedback loop is of relatively large value. If the capacitor is, for example, 0.1µF for a 10-MHz desired operating frequency, the squegging may be so severe that oscillation will completely cease for short periods, only to build up again and again. A reduction in the value will decrease the magnitude of the squegging and sometimes stop it. An excess phase shift is introduced in the loop if the capacitor becomes too small. The better cure is to decrease [the] starting gain by biasing or increasing the size of the series resistor" [5].

Our series capacitor C4 is small with a value of 2.2nF and our series resistor R3 is high with 220kΩ. For the moment we assume that squegging has different causes in BJT and MOSFET and we need different cures.

### The Neutralization Cure

Louis Alan Hazeltine in 1920 filed a patent [6] that will help us to fix our RF amp. The Neutrodyne circuit was used in tuned radio frequency vacuum tube receivers built in the 1920s. Figure 2 shows an amplifier with bridge neutralization. This neutralization circuit does not need additional inductances as the Hazeltine circuit does.
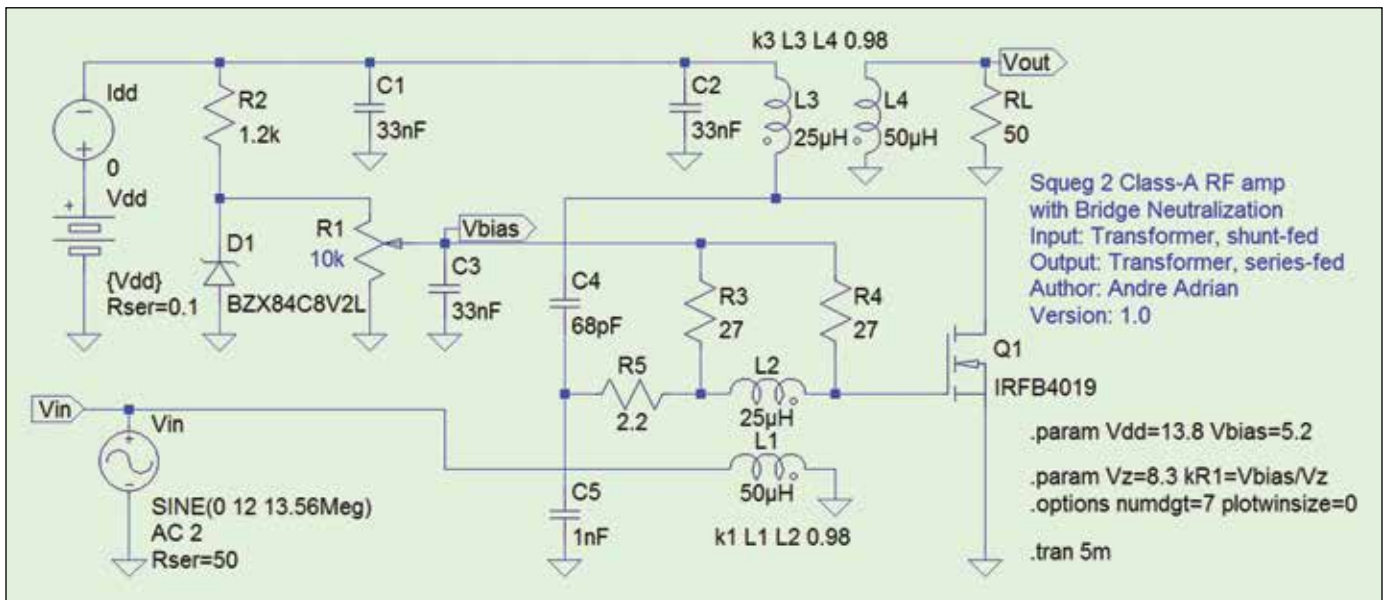


**Figure 2. Class-A radio frequency amplifier with Bridge Neutralization.**
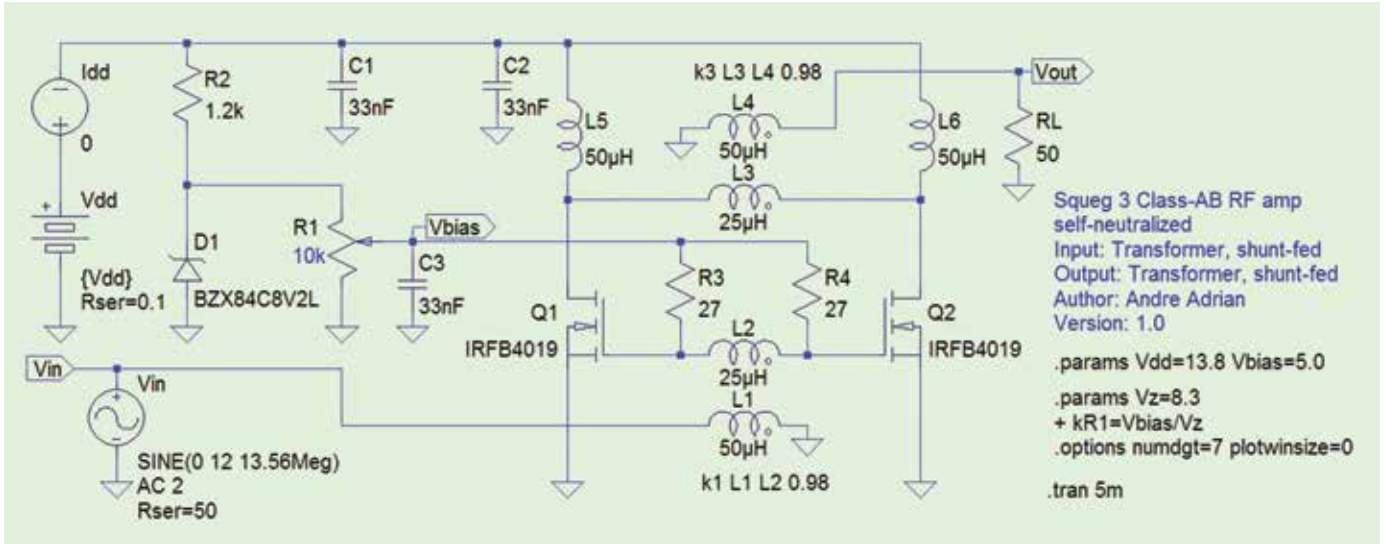
**Figure 3 • Traditional push-pull RF amplifier with built-in neutralization.**

The bias voltage circuit is the same as in Figure 1. The left hand side of the bridge is made of C4, C5 and R5. The right hand side is the MOSFET Q1. The equivalent circuit for Q1 has a distributed gate resistance Rg, a capacity Cgd between gate and drain and a capacity Cgs between gate and source. The secondary winding of the input transformer is connected to the left and right arms of the bridge. The top and bottom bridge arms go to the primary of the output transformer and ground. The bridge is in equilibrium if the ratio of C4 to C5 is equal to the ratio of Cgd to Cgs. Hazeltine did write about this in his patent: "Hence the effects of capacity coupling will have been eliminated." The bias voltage is fed to both ends of the input transformer secondary coil via R3 and R4.

The MOSFET input does not "consume" current like a BJT does. At radio frequency large currents flow in and out the MOSFET gate because the large gate source capacities Cgd and Cgs are charged and discharged at every oscillation. But these currents are reactive (wattless) currents. To proper terminate the amplifier input, the resistance of R3 plus R4 should be close to the transformed line impedance. With an input transformer inductance ratio of 50µH to 25µH or 2:1, the transformed line impedance is 25Ω.

**Better Neutralization Cure**

The Cgd capacity is voltage dependent. The class-A MOSFET amplifier neutralization is only correct for a specific input level. If we use instead of C4, C5, R5 another MOSFET of the same type as Q1 we get better neutralization. The capacities in the first MOSFET will change with the input level in the same way as they do in the second MOSFET. Using a push-pull amplifier for

HF and VHF frequencies has another benefit. The even order harmonics (2*f, 4*f …) are suppressed by the antagonistic working of both MOSFETs. Harmonics suppression requirements are fulfilled easier with a push-pull amplifier. The low-pass output filter is simpler, because there are no strong 2*f harmonics that need to be reflected or suppressed.

Figure 3 shows a traditional push-pull amp with shunt-fed output transformer L3/L4. L5 and L6 are radio frequency chokes. This circuit is self-neutralized.

As we now know one way to fix the squegging problem we will dig deeper into the problem. Why is the radio frequency signal of our first amplifier amplitude modulated? And why does the bias voltage still rise from 5.2 volts to 5.8 volts in our second amplifier as can be seen in Diagram 2?

**Cause of Amplitude Modulation**

The amplitude modulation effect is caused by the "grid bias increase." The increase of the gate voltage changes the quiescent point. More gate voltage causes more drain current in an enhancement-mode device. As the drain current rises, the voltage amplification
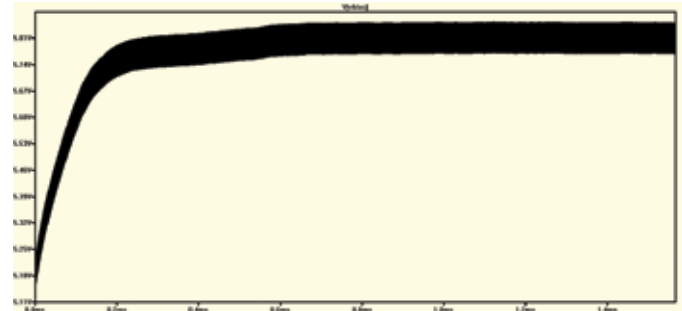


**Diagram 2 • Neutralized class-A amplifier bias voltage time curve.**

.param Vdd=13.8 Vbias=5.2
+               V1=5        V2=25
+ Crss0=303p   Crss1=64p   Crss2=27p

.model Sds SW(Ron=95m Roff=1Meg Vt=5 Vh=-1m)

Cgd model generator:
.param x1=V1 y1=Crss1/Crss0
+ x2=V2 y2=Crss2/Crss0
.func f(r) ln(y2)/ln(1+x2/x1*(exp(ln(y1)/r)-1))
.param r=f(f(f(f(f(f(-1))))))
+ c=(exp(ln(y1)/r)-1)/x1
+ rho=r+1 k=Crss0/(c*rho)

.params Vz=8.3
+ kR1=Vbias/Vz
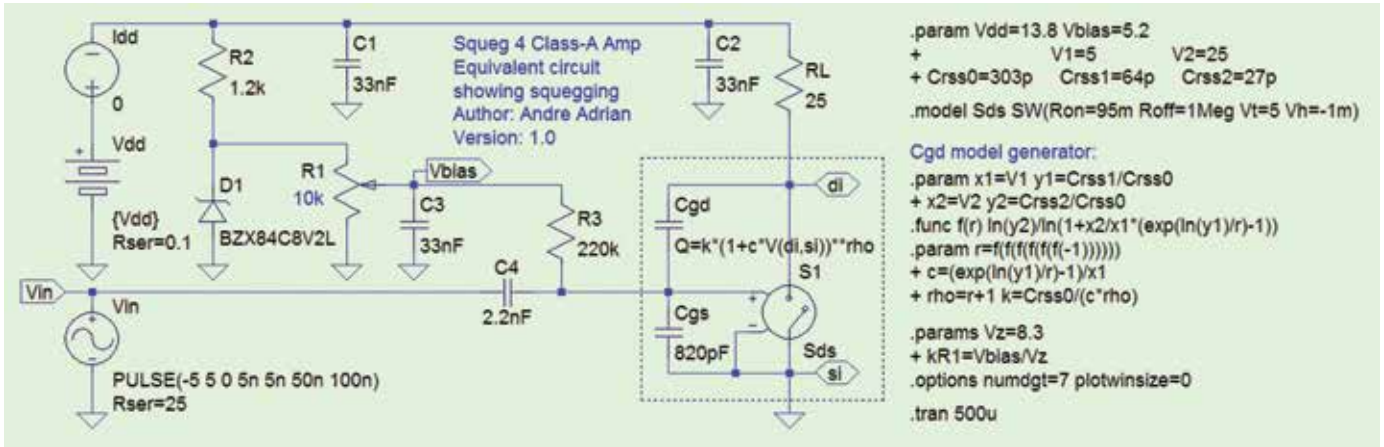.options numdgt=7 plotwinsize=0

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**Figure 4. Simple Class-A RF amplifier equivalent circuit.**

declines. If the device is an oscillator, oscillation stops when the loop gain condition of the Barkhausen stability criterion is no longer fulfilled. The bias voltage rise can move a linear mode amplifier out of the linear operation area.

The cause for the gate bias increase or gate rectification is in the differences in charge and discharge of the MOSFET internal voltage dependent Miller capacity Cgd.

For the following explanation we use a transformerless version of our first Class-A amplifier, as shown in Figure 4. For simplicity we assume that the input signal to the power MOSFET amplifier is a square wave signal. The MOSFET is replaced by the capacities Cgd, Cgs and a voltage controlled switch. Our equivalent circuit of a simulated MOSFET is even simpler than the MOSFET simulation model we used in Figure 1.

The gate coupling capacity C4 blocks any DC level the square wave input signal may have. For easy calculation we assume the supply voltage as 10 volts, the input signal duty cycle as 50%, and the signal level changes between +1 volt and -1 volt. The input signal cycle time is much smaller than the capacity charge or discharge time constant.

If the input signal is -1 volt, the MOSFET switch is open and the two capacities will charge through RL and Ri. The charge is driven by the voltage difference between drain and gate. With supply voltage 10V and input signal -1V this difference is 11V.

After the input signal changes to +1 volt, the MOSFET switch closes and the two capacities discharge. The discharge voltage for the square wave input signal is the charge voltage minus the peak-to-peak input signal voltage. Because we have different voltages for charge and discharge, the capacity of the voltage-dependent capacity Cgd will be different. Every cycle adds a little charge to Cgd, Cgs and C4. Finally the bias voltage

across C4 is large enough to switch the MOSFET permanently on. The capacities discharge. This discharge takes longer than a discharge due to the input signal. The signal input must create a stronger effect in the MOSFET than the bias circuit to make the amplifier work at all. Diagram 3 shows the saw tooth time curve of the bias voltage Vbias. The fast rising and falling slope corresponds to the oscillation phase of the squegging cycle in Diagram 1. The slow falling slope corresponds to the discharge phase of the squegging cycle.

If the Cgd charge is larger than the discharge, we have the squegging case. The opposite case, grid leak biasing [7] is possible, too. In this case the Cgd discharge is larger than the charge and the bias voltage declines.

Knowing now the cause of squegging in MOSFET circuits we can see why this phenomenon can happen in vacuum tube and BJT circuits, too. The common cathode, common emitter and common source circuits all change the phase between input and output by 180° and all have a Miller capacity between output and input.

### The Low impedance Cure

The most often used remedy for squegging is hinted in the ARRL handbook as "One form of squegging occurs when an oscillator is fed from a power supply with high source impedance" [3]. The bias voltage supply needs low impedance and must be able to sink current to ground.

BJT radio frequency amps often use a shunt diode or a byistor to provide a low impedance bias voltage source. The differential resistance of a high power diode is very small and sinking current to ground is no problem either. The bias voltage for MOSFETs is between 1.5V and 5V and of can vary by 2 volts for the same type. The MOSFET bias voltage supply must accommodate for this.

## The Low Impedance Bias Voltage Supply Circuit

The author uses a simple open loop circuit to create a variable, low impedance bias voltage. The resistor R2 and the zener diode D1 create a high impedance stabilized voltage of 8.2V. The trim pot R1 sets the bias voltage. These components are as before. The power BJT Q1 operates in the common collector circuit to provide a low impedance bias voltage output. C1 to C3 filter RF voltages. The European pnp transistor BD136 in the T0-126 housing can be replaced by any other BJT that can handle a collector current of 1.5A.

## The RF MOSFET Cure

The Miller capacity Cgd is the cause for squegging in a MOSFET. A radio frequency MOSFET has a much smaller Cgd than a power MOSFET. Microsemi produces RF MOSFETs, and they provide SPICE models that are good for MOSFET simulation at RF. The Microsemi VRF148A is a 50V, 30W, 175MHz RF MOSFET. According to the datasheet Cgd (Crss) is typically 2.6pF at Vgs=0V, Vds=50V and f=1MHz. The International Rectifier IRFB4019 datasheet tells us Cgd is typically 19pF at Vgs=0V, Vds=50V and f=1MHz.

It is possible to combine two or more squegging cures for fine performance. Two RF MOSFETs in a self-neutralized push-pull amplifier circuit can be supported by a low impedance bias voltage supply.

## Temperature Stabilization

Older power MOSFETs like the "third generation" IRF510 had a positive temperature coefficient (TC): for a constant gate voltage the drain current decreases with increasing temperature. An actual power MOSFET like the IRFB4019 has a negative TC. Without temperature stabilization thermal runaway will happen: for constant gate voltage the drain current increases with increasing temperature, which will increase the drain current again. This can destroy the MOSFET.

According to the IRFB4019 data sheet the IRFB4019 TC is typical -13mV/°C. A semiconductor diode has a TC of typical -2.2mV/°C. A negative temperature resistor (NTC) has a larger negative TC. The NTC should be in thermal contact with the power MOSFET and should influence the bias voltage to avoid thermal runaway. A good place for the NTC in the bias voltage supply circuit above is between base of Q1 and ground. The overall temperature to bias voltage characteristics are controlled by resistors in serial or in parallel to the NTC.
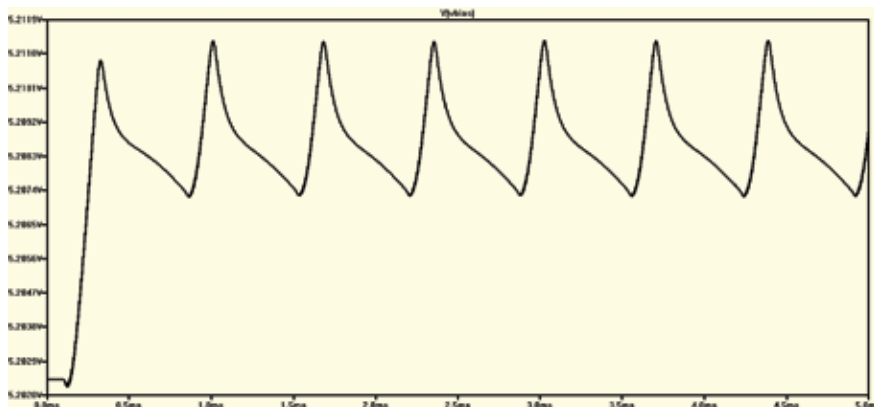


**Diagram 3 • Squegging class-A amplifier bias voltage time curve.**
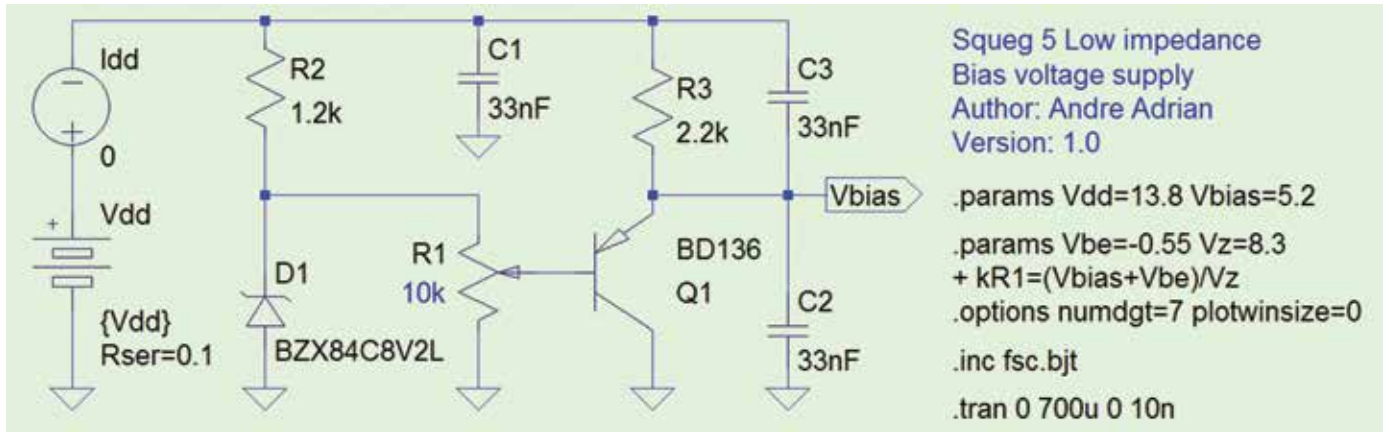
**Figure 5 • Low impedance bias voltage supply.**

### SPICE Files

The LTSpice files for this article can be found at www.andreadrian.de/pfpm.

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The author lives in Germany. He works for the German Air Traffic Control agency as senior product engineer. SPICE modeling is part of his ham hobby, but modeling in general is part of his job. His private E-mail address is Andre dot Adrian at gmx dot net.

### References

[1] http://www.dictionaryofengineering.com/definition/squegging-oscillator.html

[2] Edwin H. Armstrong; Signaling System, US Patent 1424065; Filed 27 June 1921

[3] ARRL Handbook 2013; chapter 9.3.1 LC Oscillator Circuits, page 9.14; 2013; American Radio Relay League

[4] Steven C. Hageman; Squegging - What is that, page 3; http://analoghome.com/articles.html; 2004

[5] Wes Hayward, W7ZOI; Introduction to Radio Frequency Design, section 7.3 Further LC Oscillator Topics, page 283 f.; 1995; The American Radio Relay League

[6] Louis A. Hazeltine; Method and means for neutralizing capacity coupling in Audions, US patent 1533858; Filed 28 December 1920

[7] Allen F. Carney; NAVEDTRA 14178, NEETS Module 6—Introduction to Electronic Emission, Tubes, and Power Supplies, section Grid-Leak Biasing, pg. 1-33 to 1-36; 1998; US Navy NETPDTC