Use of graphs eases transformer selection for linear supplies

Engineers generally use simple rules of thumb when selecting transformers for linear power supplies. These rules of thumb aren't universally applicable, however, and blindly using them may cause you to select a less-than-optimal transformer—and thus a less-than-optimal supply.

Thomas G Lock, *Case Western Reserve University*

If you're designing a linear power supply that will use a transformer operating at full rated load with a load-regulation factor of 0.9, traditional rules of thumb for selecting the transformer will suffice. For other applications, these rules won't necessarily be sufficient. You can account for varying power-supply operating parameters for all operating conditions by expressing the equations in the **box**, "Circuit models yield design equations," in the form of easy-to-use graphs. These equations are derived from simple models of common power-supply topologies **(Fig 1)**.

Modeling power supplies' behavior involves some simplifying assumptions. The models used to produce the graphs in this article assume that you can ignore the effects of temperature and mains-voltage variations; assume that diodes conduct abruptly, have a constant forward-voltage drop, and have a negligible series resistance; and assume that the filter capacitors have a negligible equivalent series resistance and such a large capacitance that the ripple voltage (the ac voltage

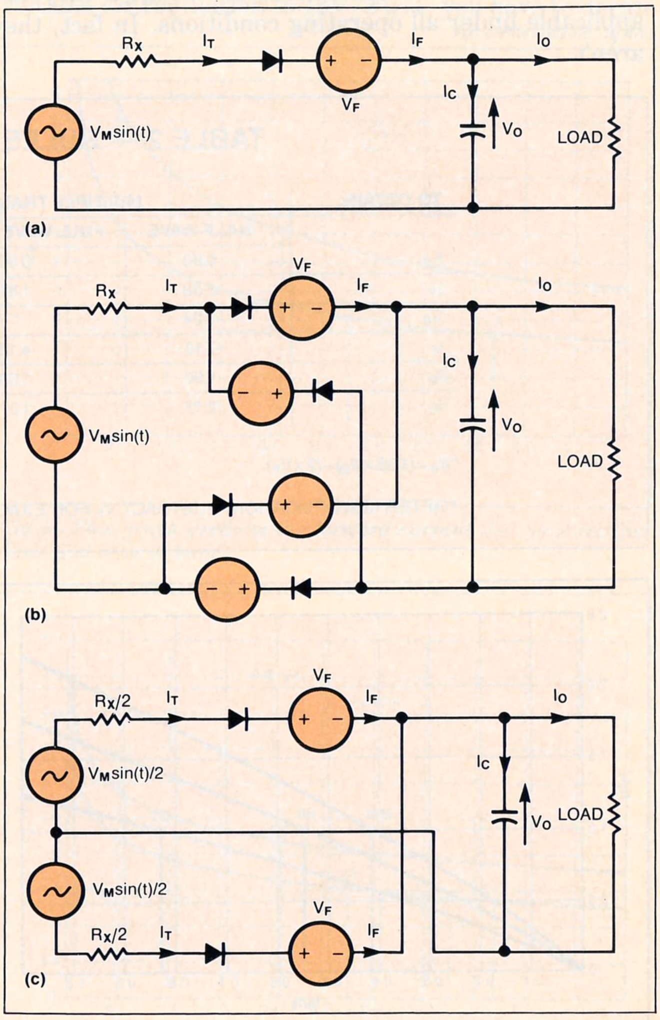


Fig 1—For each linear-power-supply topology—*half-wave* **(a,)** *full-wave bridge* **(b,)** *and full-wave center-tap* **(c)**—*you can use* **Figs 2** *through* **6** *to determine the important circuit parameters necessary for component selection.*

The transformer makers' rules don't state where the numbers come from or whether they are applicable to all operating conditions.

across the capacitor) is also negligible. The models don't ignore the internal impedance of the transformer, however, because it's too important.

Although this article uses many first-order approximations to describe power-supply operation, the design rules and graph derivations are accurate models of real power supplies and are much more accurate for a wide range of designs than are the rules of thumb. **Table 1** shows the transformer makers' simple rules of thumb for selecting a transformer for a 1A power supply with capacitive filtering. Depending on whether you're using a half-wave, full-wave bridge, or full-wave center-tap rectifier, you'll need a 2.4, 1.8, or 1.2A transformer. Although the numbers are right, the rules don't state where the numbers come from or whether they are applicable under all operating conditions. In fact, they aren't.

To understand why, you may at this point want to refer to the equations derived in the **box.** A transformer's specified voltage V_S, specified current I_S, and load-regulation factor F_X are all constant characteristics of the transformer. The conduction angle δ, dc output voltage V_O, dc output current I_O, peak diode forward current I_F, rms transformer current I_T, and rms capacitor current I_C are all variables that depend

TABLE 1—RULES OF THUMB FOR TRANSFORMER SELECTION

TRANSFORMER/RECTIFIER TYPE	FILTER TYPE	REQUIRED RMS SECONDARY RATING
HALF-WAVE	CAPACITOR	2.4×DC CURRENT
FULL-WAVE BRIDGE	CAPACITOR	1.8×DC CURRENT
FULL-WAVE CENTER-TAP	CAPACITOR	1.2×DC CURRENT

TABLE 2 — RULES OF THUMB VERIFIED

TO OBTAIN:	MULTIPLY TRANSFORMER-TYPE FACTOR:			BY:
	HALF-WAVE	FULL-WAVE BRIDGE	FULL-WAVE CENTER-TAP	
F_X	0.90	0.90	0.90	—
I_T	2.39	1.81	1.19	I_O
V_O	1.24	*	0.62	V_S**
I_F	7.16	4.12	3.58	I_O
I_O	1.00	1.00	1.00	I_O
I_C	2.17	1.51	1.31	I_O

*$V_O = (1.32 \times V_S) - (2 \times V_F)$

**AFTER MULTIPLICATION, SUBTRACT V_F FOR EXACT RESULT.

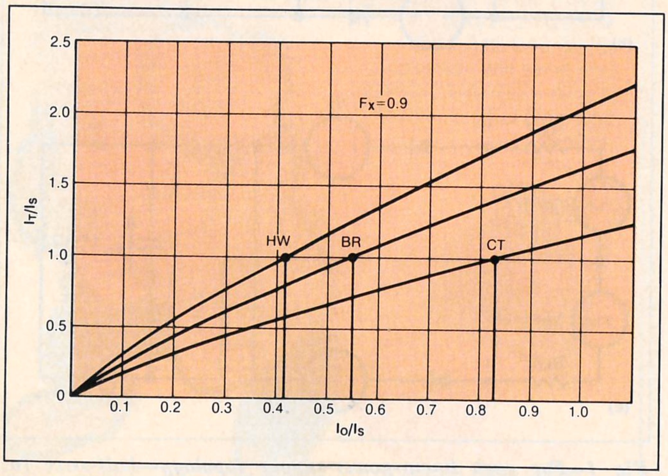


Fig 2—This graph of I_T/I_S vs *I_O/I_S shows the points where each curve crosses the I_T/I_S=1 line. These points represent the maximum allowable transformer load.*

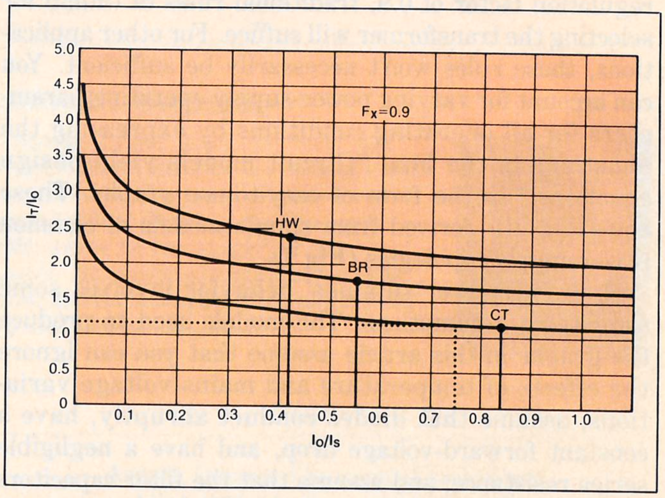


Fig 3—This graph aids in transformer selection. *I_S is the transformer maker's maximum specified transformer current.*

on how much power the supply actually delivers.

The maximum allowable power dissipation in the transformer occurs when $I_T=I_S$—when the transformer's rms current under load equals the manufacturer's rated maximum current. Plugging this condition into **Eqs 2, 4,** and **6** in the **box** generates **Table 2**'s list of relationships for a transformer dissipating its maximum allowable power. (**Table 2** expresses current in terms of I_O because engineers generally think of a power supply in terms of its output current.)

Rules verified in one instance

These results verify the transformer makers' rules of thumb: A 1A supply using a half-wave rectifier requires a 2.39A transformer; a 1A supply with a full-wave-bridge rectifier requires a 1.81A transformer; and a 1A supply with a full-wave center-tap rectifier requires a 1.19A transformer. As stated earlier, though, these results are only valid for the transformer under full load and with a load-regulation factor of 0.9.

Fig 2 plots I_T/I_S vs I_O/I_S for the three topologies; HW stands for half-wave, BR stands for full-wave bridge, and CT stands for full-wave center-tap. The graph shows the points where each curve crosses the $I_T/I_S=1$ line. These points represent the maximum allowable transformer load. The X-axis coordinates of these maximum-load points are simply the reciprocals of the 2.39, 1.81, and 1.19 factors in **Table 1**. Operating to the right of these points would overload the transformer.

Figs 3 through **6** are similar graphs; they plot I_T, V_O, I_F, and I_C with respect to I_O/I_S. All the graphs assume that the transformer's load-regulation factor F_X is 0.9. For more precise results, use the exact value of F_X for the transformer you are using and replot the graphs from the equations in the **box**.

The graphs may indicate some unexpected results. A simple example will serve as an illustration. For a 1A power supply with a 10A transformer and a half-wave rectifier, $I_O/I_S=0.1$. The graphs indicate that the capacitor rms current will be 2.875A, the transformer rms current will be 3.05A, and the diode peak forward current will be 11.6A. Assuming a diode forward-voltage drop of 1V, a 10V transformer will provide a dc output voltage of 13.5V.

To fully comprehend how to use the graphs, consider a more realistic example: a 3A, 20V power supply suitable for regulation to 15V. First, you have to decide

Text continued on pg 164

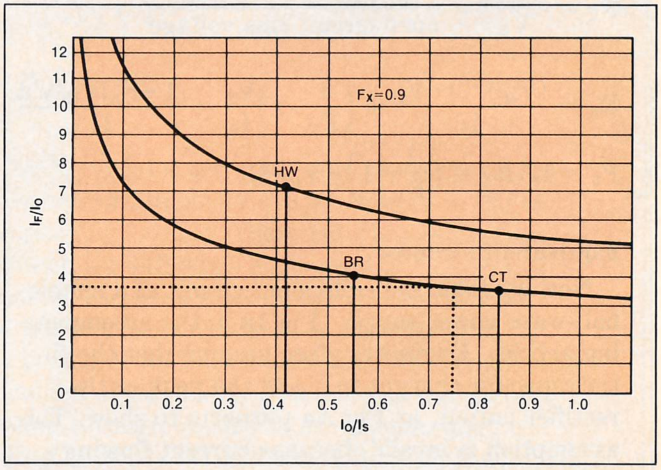


*Fig 5—**This graph predicts the forward current** that your rectifier diode will have to handle.*

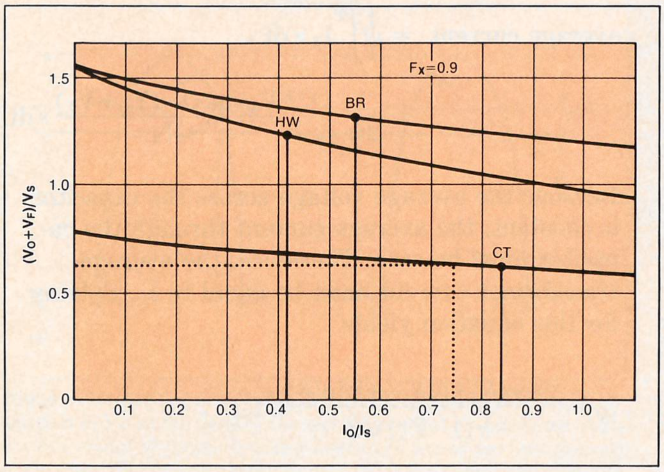


*Fig 4—**After selecting your transformer,** you can use this graph to predict your power supply's output voltage. (V_F is the rectifier's forward-voltage drop).*

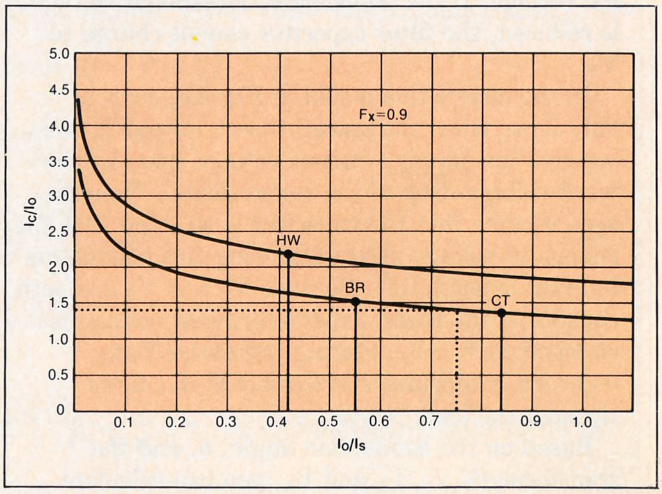


*Fig 6—**Using this graph will ensure** proper sizing of your power supply's output-filter capacitor.*

Circuit models yield design equations

To model a real transformer, you can use an ideal voltage source $V_M\sin(t)$ in series with an internal impedance R_X. In the case of a center-tap transformer, half of the voltage and half of the impedance appear on each half of the secondary winding. With the transformer connected to a load, the current flowing through R_X causes a voltage drop across R_X and reduces the transformer's terminal voltage.

Transformer makers specify a transformer's rms voltage (V_S) and rms current (I_S). The ratio of V_S to the open-circuit voltage, typically 0.8 to 0.9, is the transformer's load-regulation factor (F_X).

The transformer equations for F_X, R_X, and P_S (power) are

$$F_X = \frac{\sqrt{2}V_S}{V_M} = \frac{\text{specified rms voltage}}{\text{open-circuit rms voltage}}$$

$$R_X = \frac{(V_M/\sqrt{2})-V_S}{I_S} = \left(\frac{1}{F_X}-1\right)\frac{V_S}{I_S} = \frac{(1-F_X)V_M/\sqrt{2}}{I_S}$$

$$P_S = I_S^2\,R_X = \left(\frac{1}{F_X}-1\right)\times V_S\times I_S.$$

Equivalent circuits

Now consider the equivalent circuit of a simple half-wave power supply (**Fig 1a** in the accompanying article). Engineers often assume that the filter capacitor charges to V_M at the peak of the rectifier output, as **Fig Aa** purports to show. This assumption is invalid, because current flowing through the transformer produces a voltage drop across R_X, which reduces the transformer's terminal voltage. If the transformer's terminal voltage is reduced, the filter capacitor cannot charge to V_M.

In the alternative model in **Fig Ab,** current only flows when the transformer's output voltage exceeds the supply's output voltage (plus the forward-voltage drop of the series diode). Nonetheless, assume that the capacitor is so large that the change in voltage across it during this conduction interval is negligible. Because V_O and V_F are both constants, the transformer's terminal voltage is clamped at V_O+V_F. During the entire time $0<t<2\pi$, a constant current $I_O=V_O/R_L$ flows through the load.

Based on the conduction angle, δ, and the transformer's V_S, I_S, and F_X, you can calculate the following circuit parameters: the dc filter output voltage (V_O), the dc filter output current (I_O), the peak diode forward current (I_F), the rms transformer current (I_T), and the rms filter capacitor current (I_C). You can generally read the peak diode forward voltage V_F from the diode's data sheet if you know I_F.

First, the transformer voltage at which the rectifier begins to conduct is

$$V_M\sin(\delta) = V_O+V_F.$$

Or, in terms of the dc filter output voltage,

$$V_O = \frac{\sqrt{2}\sin(\delta)}{F_X}V_S-V_F.$$

The peak diode current occurs when the voltage across the transformer's internal impedance is at its maximum—which equals the maximum sinewave voltage minus the transformer's terminal voltage:

$$I_F = \frac{V_M-(V_O+V_F)}{R_X} = \frac{\sqrt{2}[1-\sin(\delta)]}{1-F_X}\times I_S. \qquad (1)$$

The instantaneous transformer current, I_X, during conduction is

$$I_X = \frac{V_X}{R_X} = \frac{V_M\sin(t)-(V_O+V_F)}{R_X}.$$

Integrating the instantaneous current and dividing by the period yields the average transformer current:

$$\text{average current} = \frac{1}{T}\int_0^T I_X\times dt$$
$$= \frac{1}{2\pi}\int_\delta^{\pi-\delta}\frac{V_M\sin(t)-(V_O+V_F)}{R_X}\times dt.$$

Because the average voltage across the capacitor is constant, the average current through the capacitor must be zero. Therefore, the average transformer current must be equal to I_O. Solving for this equation yields

$$I_O = \frac{2\cos(\delta)+(2\delta-\pi)\sin(\delta)}{\pi(1-F_X)\sqrt{2}}\times I_S.$$

Plugging the instantaneous current into the standard rms integral equation gives

$$\text{rms current} = \sqrt{\frac{1}{T}\int_0^T I_X^2 \times dt}$$

$$= \sqrt{\frac{1}{2\pi}\int_{\delta}^{\pi-\delta}\left(\frac{V_M\sin(t)-(V_O+V_F)}{R_X}\right)^2 \times dt},$$

which yields

$$I_T = \frac{1}{1-F_X}\sqrt{\frac{1}{\pi}[(\pi-2\delta)[\frac{1}{2}+\sin^2(\delta)]-\frac{3}{2}\sin(2\delta)] \times I_s}. \quad (2)$$

Although the average current through the filter capacitor is zero, the capacitor does charge and discharge. Its rms current is

$$I_C = \sqrt{I_T^2 - I_O^2}.$$

The equations for full-wave bridge and full-wave center-tap rectifier circuits are simple extensions of the half-wave rectifier equations. Consider the full-wave bridge power-supply equivalent circuit first (**Fig 1b** in the accompanying article). There are two differences between the full-wave bridge and the half-wave circuits:

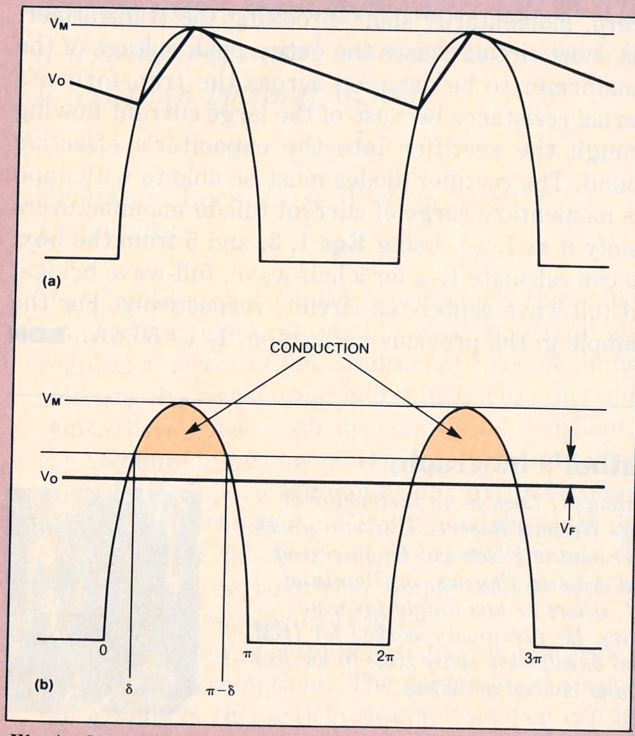


***Fig A—You are incorrect if you assume** that the filter capacitor charges to V_M at the peak of the rectifier output as **Aa** shows. **Ab's** correct model of filter-capacitor operation shows current flowing only when the transformer's output voltage exceeds the supply's output voltage (plus the forward-voltage drop of the series diode).*

The full-wave bridge supply can have two diode forward-voltage drops at any time, and the period of the transformer current is π instead of 2π.

These differences result in the following equations for the full-wave bridge rectifier circuit:

$$V_M\sin(\delta) = V_O+2V_F$$

$$V_O = \frac{\sqrt{2}\sin(\delta)}{F_X}V_S-2V_F$$

$$I_F = \frac{\sqrt{2}[1-\sin(\delta)]}{1-F_X}\times I_S \quad (3)$$

$$I_O = \frac{\sqrt{2}[2\cos(\delta) + (2\delta-\pi)\sin(\delta)]}{\pi(1-F_X)}\times I_S$$

$$I_T = \frac{1}{1-F_X}\sqrt{\frac{2}{\pi}[(\pi-2\delta)[\frac{1}{2}+\sin^2(\delta)]-\frac{3}{2}\sin(2\delta)] \times I_S} \quad (4)$$

$$I_C = \sqrt{I_T^2-I_O^2}.$$

Next, consider the equivalent circuit for a full-wave center-tap power supply (**Fig 1c** in the accompanying article). There are four differences between the full-wave center-tap and half-wave circuits: The peak transformer voltage is $V_M/2$, the transformer impedance in each leg is $R_X/2$, the period of the current charging the capacitor is π instead of 2π, and I_T is defined as the current flowing through one leg of the transformer, resulting in two paths of current through the rectifier diodes to the filter capacitor.

These differences result in the following equations for the full-wave center-tap rectifier circuit:

$$V_M\sin(\delta)/2 = V_O+V_F$$

$$V_O = \frac{\sin(\delta)}{F_X\sqrt{2}}V_S-V_F$$

$$I_F = \frac{\sqrt{2}[1-\sin(\delta)]}{1-F_X}\times I_S \quad (5)$$

$$I_O = \frac{\sqrt{2}[2\cos(\delta)+(2\delta-\pi)\sin(\delta)]}{\pi(1-F_X)}\times I_S$$

$$I_T = \frac{1}{1-F_X}\sqrt{\frac{1}{\pi}[(\pi-2\delta)[\frac{1}{2}+\sin^2(\delta)]-\frac{3}{2}\sin(2\delta)] \times I_S} \quad (6)$$

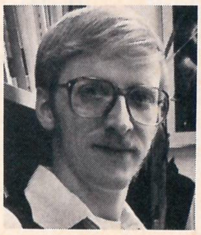
$$I_C = \sqrt{2I_T^2-I_O^2}.$$

which topology to use. Supposing you use a full-wave bridge rectifier, you can see by looking at **Fig 3** that you need at least a 5.4A transformer. **Fig 4** indicates that the transformer should be rated at about 16.7V (assuming 1V diode forward-voltage drops). If you use a full-wave center-tap rectifier, you need a 3.6A, 33.9V transformer.

In this case, the center-tap rectifier circuit is the topology of choice because of the availability of a stock 4A, 36V transformer (Stancor P-8673). Going back to the graphs armed with this transformer's parameters, you can see that $I_O/I_S=0.75$ (indicated by a dotted line in **Fig 3**). **Fig 3** also indicates that the transformer rms current will be 3.7A. **Fig 4** predicts a dc output voltage of 21.8V, resulting in the voltage regulator dissipating 20.4W. **Fig 5** shows that the diodes must be rated for a repetitive peak forward current of 11.1A, and **Fig 6** indicates that the filter capacitor must be able to withstand an rms current of 4.2A.

You should be aware of one other salient parameter when choosing a transformer. When the power supply is first turned on, the voltage across the filter capacitor is zero, momentarily short-circuiting the transformer. This short circuit causes the entire peak voltage of the transformer to be dropped across the transformer's internal resistance because of the large current flowing through the rectifier into the capacitor's effective ground. The rectifier diodes must be able to withstand this momentary surge of current (diode manufacturers specify it as I_{FSM}). Using **Eqs 1, 3,** and **5** from the **box,** you can calculate I_{FSM} for a half-wave, full-wave bridge, and full-wave center-tap circuit, respectively. For the example in the previous paragraph, $I_{FSM}=56.6A$. **EDN**

Author's biography



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Article Interest Quotient (Circle One)
High 485 Medium 486 Low 487

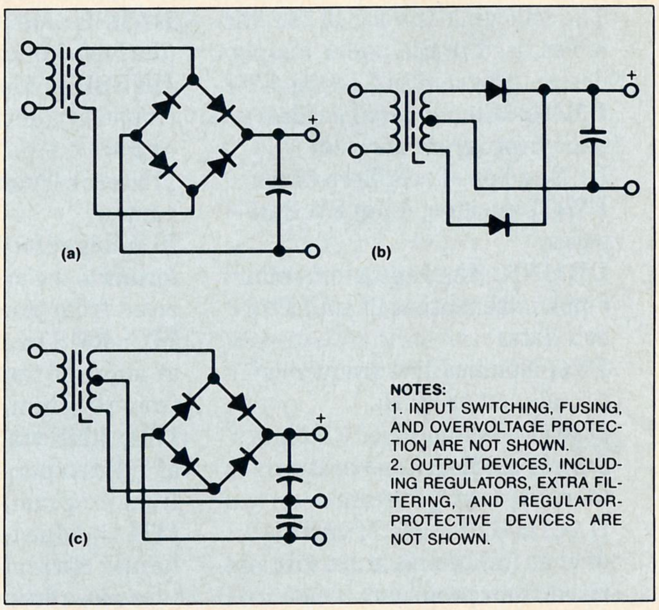
Basic program simplifies design of linear power supplies

The Basic program presented here can spare you a lot of the math involved in designing linear power supplies. The program prompts you for design specs and then generates the parameters for a workable design.

George Sayer, *Consulting Engineer*

Although the techniques for linear-power-supply design have gradually improved over the years, they still have one chief shortcoming—they require you to perform major mathematical manipulations for each supply design or design change. The Basic program presented here can spare you the math. It asks you simple questions and then generates the parameters for a supply design. The program allows you to use standard off-the-shelf components, so there's no need for you to perform any mathematical manipulations at all.

Your first task in designing a power supply, as in any design, is to establish your objectives. For example, you want the supply to function properly under all operating conditions. Such conditions will include high and low line voltages as well as varying temperatures. You need to keep in mind that the transformer's electrical resistance and core losses will generate heat and that the regulator, the rectifiers, the surge resistor (if you use one), and the enclosure will also contribute to the heat rise.



NOTES:
1. INPUT SWITCHING, FUSING, AND OVERVOLTAGE PROTECTION ARE NOT SHOWN.
2. OUTPUT DEVICES, INCLUDING REGULATORS, EXTRA FILTERING, AND REGULATOR-PROTECTIVE DEVICES ARE NOT SHOWN.

***Fig 1—The power-supply-design program can help you design** full-wave-bridge (FWB) (a) and full-wave-center-tap (FWCT) (b) supplies, and you can adapt the program's FWCT analysis to a dual complementary supply (DCS) (c).*

Besides being aware of electrical and temperature considerations, you need to take into account mechanical considerations (such as space for the supply) and shock and vibration problems. Finally, you must consider factors such as troubleshooting, the cost and ease of obtaining parts, the availability of alternate sources for

The program analyzes supply operation under high and low line-voltage conditions while the transformer is at ambient and at peak temperatures.

parts, and the parts' reliability and compliance with safety standards.

The power-supply design program in **Listing 1** (pg 241) analyzes supply operation under high and low line-voltage conditions while the transformer is at ambient and at peak temperatures. Because it specifies off-the-shelf components, the program also partially solves the problems of parts availability and alternate sources.

The program compensates for regulation increase with temperature and for high and low line voltages. It is written in GW-Basic, version 2.02, which can run on many microprocessors. Its performance relies on two assumptions—the transformer regulation spec is a room-temperature figure (no warmup), and the leakage inductance in the transformer and series loss in the filter capacitor are negligible.

You can use the program in **Listing 1** to design full-wave-bridge (FWB) and full-wave-center-tap (FWCT) supplies, and you can adapt the program's FWCT analysis to a dual complementary supply (DCS) (**Fig 1**). The program uses the diode count, D, to compensate for differences between the FWCT and FWB circuits. K, the ratio of the transformer output resistance in the actual circuit to the output resistance in the manufacturer's test circuit, compensates for output-resistance modifications in the FWCT circuit.

The program begins by asking you to enter the transformer's nominal input voltage specification (110V, 115V, 117V, 120V, 230V, etc). Next, you define worst-case high-line and low-line voltages. Then you enter the line frequency. If your supply is intended for

Glossary of program variables

The following is a list of the variables used in the power-supply design program in **Listing 1.**

CMIN: Min permissible filter capacity (program derived)

D: Number of rectifiers (2 for FWCT designs; 4 for FWB designs)

DBMNR: The regulator's min ripple attenuation (manufacturer's data)

FRQ: Nominal line frequency (usually 50 or 60 Hz.)

HACC: Half-angle of current flow at ambient temperature (derived from program)

HACH: Half-angle of current flow at full temperature rise (derived from program)

ICRMS: RMS capacitor current (derived from program)

IDC: Full load current required by the application

IDCL: Regulator current limit specification (derived from program)

IDPR: Repetitive peak rectifier current (derived from program)

IDRMS: RMS value of diode current (derived from program)

IINRSH: Max inrush current (derived from program)

IINRSHA: Max inrush current (rounded) (derived from program)

I1N(etc): Points on rectifier curves

IS1: Suggested current of transformer's secondary winding (derived from program)

ITC: RMS transformer current at ambient temperature (derived from program)

ITH: RMS transformer current at full temperature rise (derived from program)

ITHA: Adjusted RMS transformer current at full temperature rise (derived from program)

ITRTD: Actual rated current used in program for transformer's secondary windings (derived from program)

ITRTD1: Actual rated current for transformer's secondary winding (manufacturer's data)

ITRDT2: Adjusted ITRTD1 (derived from program)

I1X(etc): Points on rectifier curves

K: Ratio of the transformer output resistance used to the output resistance in the configuration the manufacturer specifies (derived from program)

N: Number of passes through a subroutine in the program

NRGNC: Estimated new transformer regulation to lower inrush current

PD: Individual rectifier power dissipation (derived from program)

PRGMX: Max regulator power dissipation (derived from program)

PRSRGP: Power dissipated in surge resistor (derived from program)

PTPRS: Predicted transformer temperature rise (derived from program)

RDFA: Rectifier forward resistance (derived from program)

RECT1: Rectifier constant (derived from program)

RECT2: Rectifier constant (derived from program)

RECT3: Rectifier constant (derived from program) an international market, you must evaluate the design at both 50 and 60 Hz. To proceed, you then enter the required full-load current value.

At this point, the program determines the regulator's minimum current limit. Using data-sheet information, you select a trial regulator and enter its maximum and minimum output voltages, its dropout voltage at the maximum expected load current (I_{DC}), and its minimum ripple attenuation. Next, you enter the allowable peak-to-peak ripple voltage (in millivolts) at the regulator output.

The program then displays the maximum filter-output ripple on the monitor; if the ripple is more than 20% of the output voltage, the program requests that you enter a lower output ripple voltage. The program's math requires that the ripple be less than 20%, a reasonable figure for optimum supply performance.

The program then asks you to define the type of rectification (FWB or FWCT) by entering either 4 or 2, respectively. These numbers establish the rectifier count. The program then asks if you'll be using 1N4001 diodes. If the answer is yes, the program automatically enters the values for RECT1 through RECT4. If the answer is no, the program branches to a routine that asks you to specify a rectifier type and to enter some points on the rectifier's maximum and minimum current-vs-voltage curves. The program then determines the values of RECT1 through RECT4 and returns from the routine.

At this point, the program approximates the transformer's output-voltage requirements, and it inquires whether the transformer will have one or two secon-

RECT4: Rectifier constant (derived from program)
RGNC: Transformer regulation at ambient temperature (derived from program)
RGNC2: Transformer regulation at ambient temperature (manufacturer's data)
RGNH: Transformer regulation at TPRS (derived from program)
RIP: Max allowed filter output ripple (derived from program)
RIPA: RIP rounded to two decimal places (derived from program)
RIPO: Allowable regulator p-p ripple output (derived from program)
RIPOM: Allowable regulator p-p ripple output in millivolts
RSRG: Surge resistor in transformer secondary (derived from program)
RSRGP: RSRG moved to transformer primary (derived from program)
S: Number of transformer secondaries (manufacturer's data)
TPRS: Transformer temperature rise (manufacturer's data)
VDFA: Effective rectifier voltage drop (derived from program)
VDMN: Min rectifier voltage drop with IDPR (derived from program)
VDMNR: Min allowed rectifier reverse voltage (derived from program)
VDMX: Max rectifier voltage drop with IDPR (derived from program)
VFLMN: Min full-load filter output voltage (derived from program)
VFLMX: Max full-load filter output voltage (derived from program)
VHL: Highest line voltage expected in the application
VLL: Lowest line voltage expected in the application
V1N(etc): Points on rectifier curves
VNL: Nominal transformer input voltage (manufacturer's data)
VNLMX: Max no-load filter output voltage (derived from program)
VR: Max regulator dropout voltage at I_{DC} (manufacturer's data)
VROM: Max regulator output voltage (manufacturer's data)
VTR: Voltage of transformer's secondary winding (obtained from a heuristic formula, derived from program)
VTRS: Suggested voltage for transformer's secondary winding (derived from program)
VTRTDC: Rated voltage used in program for transformer's secondary winding (derived from program)
VTRTDC1: Actual rated voltage of transformer's secondary winding (manufacturer's data)
VTRTDC2: Rated voltage of transformer's secondary winding at ambient temperature (derived from program)
VTRTDH: Rated voltage of transformer's secondary winding at full temperature rise (derived from program)
V1X(etc): Points on rectifier curves
XC: Variable used to determine HACC (derived from program)
XH: Variable used to determine HACH (derived from program)

You can use the program to design full-wave-bridge (FWB), full-wave-center-tap (FWCT), and DCS or center-tapped-bridge supplies.

dary windings (power-supply transformers usually have two secondary windings). After a few more internal calculations, the program displays the suggested voltage and current for the transformer's secondary windings and asks you to choose a transformer from manufacturers' catalogs. The program then asks for the actual voltage and current ratings of the selected part's secondary windings. The program assumes that when you choose from a list of transformers with two secondary windings (S=2), the manufacturer's test circuit has the two secondaries in parallel.

For further computations, the program adjusts the voltage and current values according to the number of secondary windings and rectifiers. The program then requests the transformer's temperature rise at full load and the transformer's regulation. After receiving that information, the program computes many of the required output values, including the maximum inrush current. If the inrush current is too high for the selected rectifiers, the program requests a higher value of regulation and determines a corresponding surge-resistor value. The program then recomputes all the main output values and displays a new inrush current. You repeat this sequence until you have an acceptable inrush-current value.

The program then asks you to ready the printer. It prints your inputs first (in the order entered) and then prints the names of the components. Next, it prints all the output values. If VFLMN (the minimum full-load filter output voltage) is less than VROM+VR (the

```
     INPUTS
     VNL= 115       VHL= 130       VLL= 95        FRQ= 60        IDC= .5
     VROM= 5.2      VROMN= 4.8     VR= 2          DBMNR= 62      RIPO= .0004
     DIODES= 2      SCNDRS.= 2     VTRTDC1= 8     ITRTD1= 1.6    TPRS= 46
     RGNC2= .21     REGLTR= LM7805C               RECTFRS=  1N4001 SERIES DIODES
     XFMR= TRIAD-UTRAD FS16-800
     OUTPUTS
     TRANSFORMER CURRENT AT REQUIRED FULL LOAD, AC AMPS = .82
     MAXIMUM ALLOWABLE CURRENT OUTPUT (WHEN LOAD INCREASED SO THAT
     TRANSFORMER LOAD = LOAD AT FULL TEMP. RISE), DC AMPS =  .86
     MINIMUM CAPACITY OF FILTER CAPACITOR, MICROFARADS =  4800
     RMS CAPACITOR CURRENT, AMPS =  .68
     MAX. NO LOAD FILTER OUTPUT VOLTAGE, VOLTS =  15.5
     MAX. FULL LOAD FILTER OUTPUT VOLTAGE, VOLTS =  11.7
     MIN. FULL LOAD FILTER OUTPUT VOLTAGE, VOLTS =  7.3
     MAX. REGULATOR POWER DISSIPATION, WATTS = 3.3
     INDIVIDUAL RECTIFIER POWER DISSIPATION, WATTS = .27
     MINIMUM RECTIFIER REVERSE VOLTAGE, VOLTS = 31
     MAX. INRUSH CURRENT, AMPS = 9
     REPETITIVE PEAK RECTIFIER CURRENT, AMPS = 1.8
     SURGE RESISTOR (IF IN XFRMR PRIMARY), OHMS = 0
     POWER DISSIPATED IN SURGE RESISTOR, WATTS = 0
(a)  PREDICTED TRANSFORMER TEMPERATURE RISE, DEG C = 31
```

```
     INPUTS
     VNL= 115       VHL= 130       VLL= 95        FRQ= 60        IDC= .5
     VROM= 5.2      VROMN= 4.8     VR= 2          DBMNR= 62      RIPO= .0004
     DIODES= 4      SCNDRS.= 2     VTRTDC1= 8     ITRTD1= 1.6    TPRS= 46
     RGNC2= .21     REGLTR= LM7805C               RECTFRS=  1N4001 SERIES DIODES
     XFMR= TRIAD-UTRAD FS16-800
     OUTPUTS
     TRANSFORMER CURRENT AT REQUIRED FULL LOAD, AC AMPS = .88
     MAXIMUM ALLOWABLE CURRENT OUTPUT (WHEN LOAD INCREASED SO THAT
     TRANSFORMER LOAD = LOAD AT FULL TEMP. RISE), DC AMPS =  1.01
     MINIMUM CAPACITY OF FILTER CAPACITOR, MICROFARADS =  5300
     RMS CAPACITOR CURRENT, AMPS =  .76
     MAX. NO LOAD FILTER OUTPUT VOLTAGE, VOLTS =  15.5
     MAX. FULL LOAD FILTER OUTPUT VOLTAGE, VOLTS =  11.6
     MIN. FULL LOAD FILTER OUTPUT VOLTAGE, VOLTS =  6.7
     VFLMN < (VROM+VR). THIS REQUIRES EITHER LESS ALLOWABLE
(b)  OUTPUT RIPPLE OR HIGHER TRANSFORMER VOLTAGE, OR BOTH.
```

Fig 2—These program outputs give the parameters for a successful design *of a 5V/0.5A supply. The output in* ***(a)*** *gives the values for an FWCT-type design. The output for the FWB design* ***(b)*** *reports that the extra diodes cause low regulator input voltage under low line-voltage conditions.*

maximum regulator output voltage plus the maximum regulator dropout voltage at I_{DC}), the program generates the message: "VFLMN<(VROM+VR); this requires either less allowable output ripple or higher transformer voltage, or both." You must then check each of the output values against the component specifications to make sure you've chosen acceptable components. **Fig 2** gives samples of the program's output for a 5V/0.5A supply.

In addition to helping you design FWCT and FWB circuits, the program can accommodate a third circuit—the dual complementary supply (DCS), also known as the center-tapped bridge. The DCS is a popular circuit for applications that require positive and negative voltages. The most useful design approach to the DCS is to program as if you have two FWCT supplies in parallel. You simply add the load currents and then analyze the supply as a single FWCT circuit. You should then proportion the capacitor sizes according to the load current. For example, if the program provides 1000 μF and one supply current is 0.1A and the other is 0.3A, the corresponding capacitor sizes should be 250 μF and 750 μF. The capacitor voltages and ripple voltages do not change. The regulator power dissipations will be proportional to the load current and should be divided as the capacitor values are. **EDN**

References

1. Lieders, A, "Single-phase rectifier circuits with CR filters, Part 1—Theory," *Electronic Components and Applications,* Vol 1, No 3, May 1979, pgs 163-165.

2. Lieders, A, "Single-phase rectifier circuits with CR filters, Part 2—Design procedures," *Electronic Components and Applications*, Vol 1, No 4, August 1979, pgs 216-230.

3. Richards, J C S, "Simplified design of dc power supplies," *Wireless World,* Vol 87, August 1981, pgs 35-37. (See also Vol 88, March 1982, pgs 67-68.)

4. Schade, O H, "Analysis of rectifier operation," *Proceedings of the Institute of Radio Engineers,* Vol 31, No 7, July 1943, pgs 341-361.

You can obtain formula derivations not found in the above references directly from the author at 858 NW 8th Ave Dr, Hillsboro, OR 97124.

Author's biography

George Sayer is a consulting engineer in Hillsboro, OR; he specializes in power-supply design. George holds AB and BSEE degrees from Columbia University and an MS in applied math from Adelphi University. He was previously employed by Grumman, Western Electric, and a number of other companies. George is a licensed professional engineer in Oregon and is also a part-time stockbroker.

Article Interest Quotient (Circle One)
High 482 Medium 483 Low 484

LISTING 1

```
10 PRINT "****************************************"
20 PRINT "    LINEAR FULL WAVE REGULATED POWER"
30 PRINT "    SUPPLY DESIGN WITH OFF-THE-SHELF"
40 PRINT "    COMPONENTS, FOR USE WITH GW-BASIC"
50 PRINT "       BY GEORGE SAYER - 08-25-86"
60 PRINT "****************************************":PRINT
70 INPUT "NOMINAL TRANSFORMER INPUT VOLTAGE (EG. 115,120,230), VOLTS"; VNL
80 INPUT "HI-LINE VOLTAGE (EG. 130, 250), VOLTS"; VHL
90 INPUT "LO-LINE VOLTAGE (EG. 95, 190), VOLTS"; VLL:PRINT
100 INPUT "LINE FREQUENCY (EG. 50, 60)";FRQ:PRINT
110 INPUT "REQUIRED FULL LOAD CURRENT, AMPS "; IDC:PRINT
120 IDCL=IDC/.65:IDCL=IDCL*100:IDCL=CINT(IDCL):IDCL=IDCL/100
130 PRINT "CHOOSE REGULATOR WITH CURRENT LIMITING (AMPS)=";IDCL;"OR GREATER":PRI
NT:INPUT "REGULATOR CHOSEN ";RG$:PRINT
140 INPUT "MAX. REGULATOR OUTPUT VOLTAGE (NOMINAL + TOLERANCE), VOLTS "; VROM
150 INPUT "MIN. REGULATOR OUTPUT VOLTAGE (NOMINAL - TOLERANCE), VOLTS "; VROMN
160 INPUT "MAX. REGULATOR DROPOUT VOLTAGE AT MAX. LOAD, VOLTS"; VR:PRINT
170 INPUT "REGULATOR'S MIN. RIPPLE ATTENUATION, DB "; DBMNR
180 INPUT "ALLOWABLE P-P RIPPLE AT REGULATOR OUTPUT, MILLIVOLTS "; RIPOM
190 RIPO=RIPOM/1000
200 RIP = RIPO*(10^(DBMNR/20))
```

Listing continued on pg 242