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ULTRA HIGH-SPEED ICs

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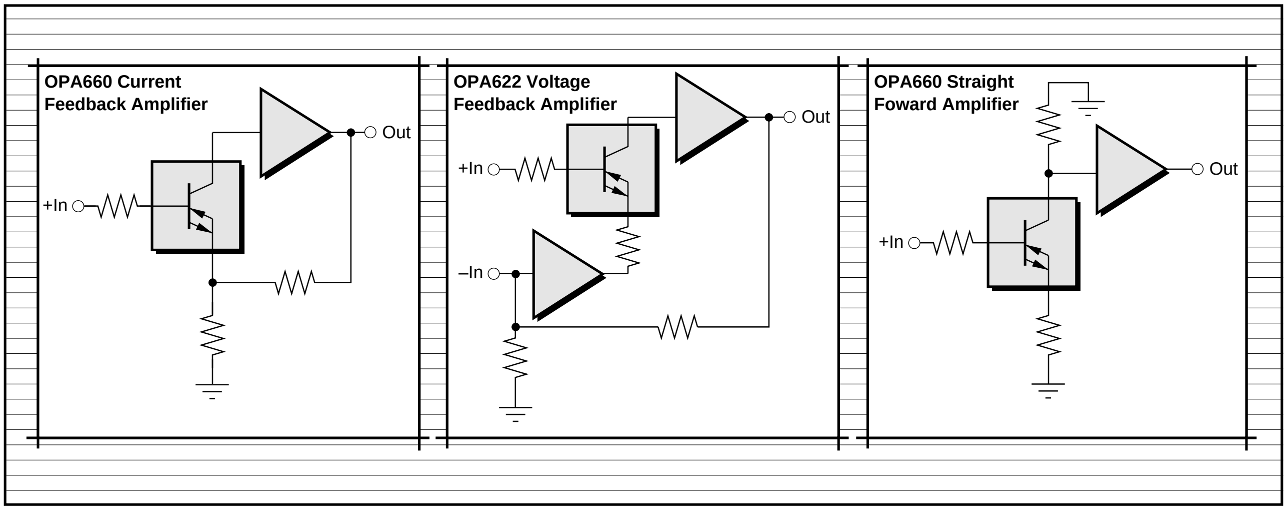

QUASI-IDEAL CURRENT SOURCE

In addition to their actual operation parameter transconductance, active electronic key components such as vacuum tubes, field effect transistors, and bipolar transistors demonstrate diverse negative parameters. In applying the so-called Diamond structure, the user can obtain an improved current source with reduced disturbance parameters, as well as a programmable transconductance independent of temperature. Standard applications for the Diamond current source (DCS) can be found in buffers, operational amplifiers with voltage or current feedback, and transconductance amplifiers. The DCS simplifies the design of electronic circuits with bandwidths of up to 400MHz and slew rates of 3000V/µs with a low supply current of several mA.

VOLTAGE-CONTROLLED CURRENT SOURCES

For analog signal processing, especially current or voltage gain, previous electronic circuit techniques primarily used vacuum tubes, while today they use field effect or bipolar transistors. The triode illustrated in Figure 1 is representative of the various vacuum tubes, while the N-channel FET represents the FET variations (junctions, insulated gates, depletion, enhancements, P-channels, and N-channels), and a NPN transistor represents the range of bipolar transistors. Triodes, N-J FETs, and NPN transistors are compared with the Diamond current source (DCS). The common elements of all of these active elements are a relatively high-impedance input electrode 1 (grid, gate, basis), a low-impedance

COMPONENT	PARAMETER	TYPICAL VALUE
Triode	Grid Bias Voltage	0 to 10V
	Anode Bias Voltage	20 to 1kV
	Grid Current	nA to µA
	Anode Bias Current	µA to A
	G/K Resistance	kΩ to MΩ
	A/K Resistance	kΩ to MΩ
	Trans Grid Action	1 to 20%
N-J FET	Gate Voltage	0 to –10V
	D/S Voltage	0 to 100V
	Gate Current	fA to µA
	D Bias Current	µA to A
	G/S Resistance	MΩ to GΩ
	D/S Resistance	kΩ to MΩ
	Inverse Amplification	1 to10%
NPN Transistor	Basis Voltage	0.5 to 0.8V
	K/E Voltage	0.5 to 100V
	Basis Current	µA to mA
	K Bias Current	µA to A
	B/E Resistance	kΩ
	K/E Resistance	kΩ
	Inverse Amplification	0.1 to 1%
DCS	V_{OFF1}	–2 to +2mV
	V_{OFF3}	0V
	I_{BIAS1}	nA to µA
	I_{BIAS3}	µA
	R_{12}	kΩ to MΩ
	R_{32}	kΩ
	V_{R31}	<0.1%

TABLE I. Typical Disturbance Parameters of the Voltage-Controlled Current Sources.

input and output electrode 2 (cathode, source, emitter), and a high-impedance output electrode 3 (anode, drain collector). Thus all of these elements can be treated as special voltage-controlled current sources (VCCS = Voltage-Controlled Current Source). The limitation “special” refers to the low-impedance input and output electrode 2. The most important relation between the electrodes 1, 2, and 3 is the transconductance gm. For instance, the transconductance describes the change of the output signal (V_{OUT}) dependent upon the input signal (V_{IN}).

$$V_{OUT} = V_{IN} \times gm \times R_{OUT} \quad (1)$$

To operate each VCCS, it is necessary to adjust the DC quiescent current or voltage individually (see Figure 1).

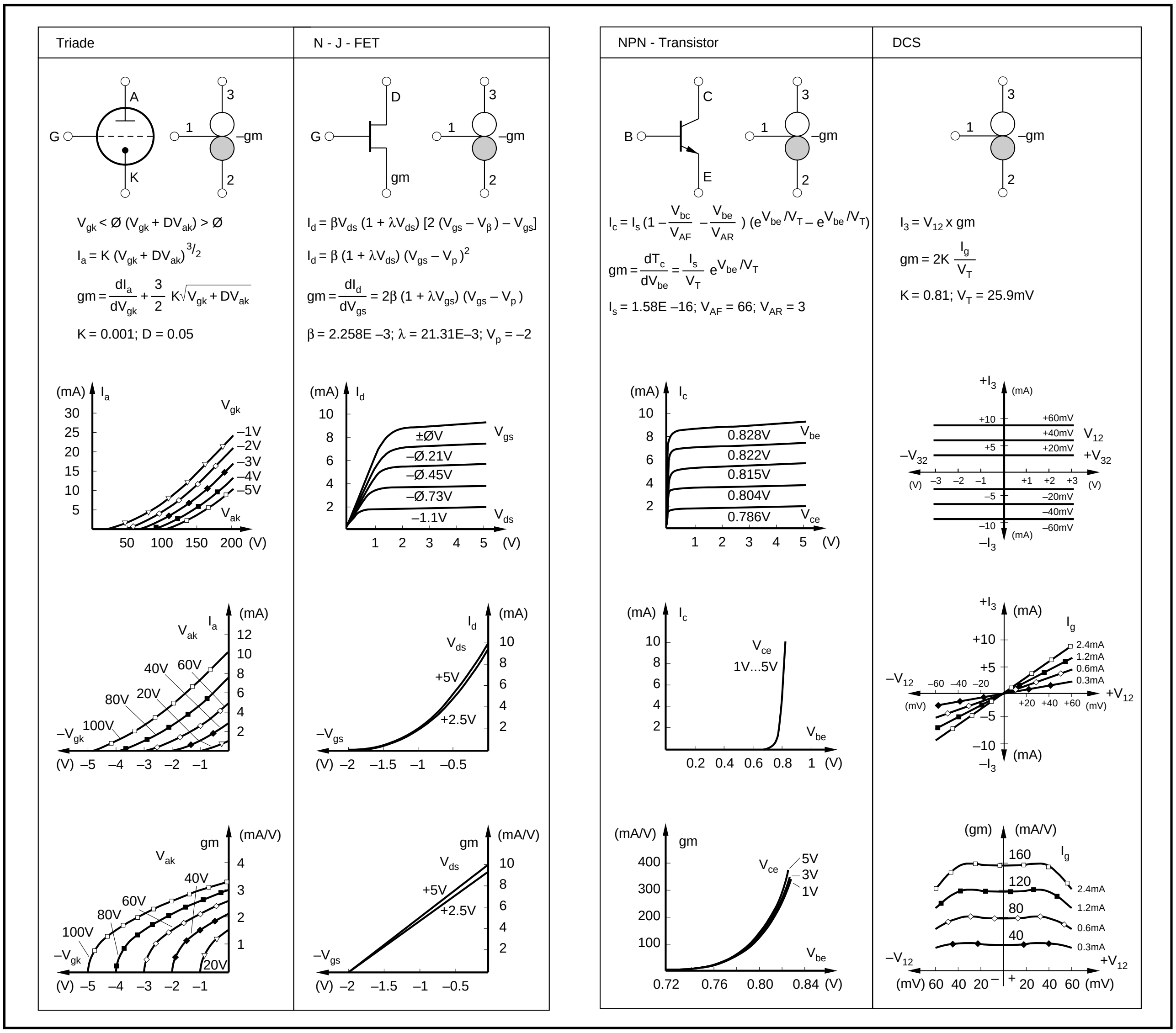

FIGURE 1. Comparison Between Voltage-Controlled Current Source (VCCS) and Diamond Current Source (DCS).

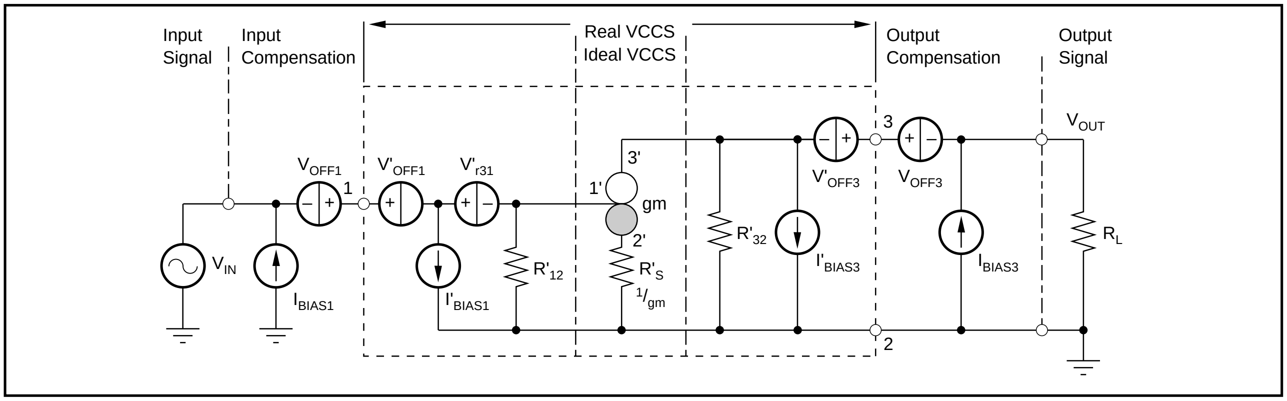

FIGURE 2. Internal and External Substitute Circuitry of a Voltage-Controlled Current Source.

Figure 2 illustrates the inner and outer substitute circuitry of a voltage-controlled current source VCCS. According to the circuitry, the VCCS (1, 2, 3) consists of an inner ideal VCCS (1', 2', 3') with transconductance gm and a row of inner disturbance parameters (V', I' , R'), which determine, among other things, the adjustment of the DC point. Table I shows a rough overview of the disturbance parameters. Almost all disturbance parameters are subject to tolerances between units and show dependent temperature behavior.

Figure 2 also illustrates the correction parameters (V_{OFF1}, V_{OFF3}, I_{BIAS1}, and I_{BIAS3}), which are required primarily to compensate the internal disturbance parameters. The correction parameters, however, do not correct the effects of the internal disturbance parameters (R'_{12}, R'_{32}) and the output voltage feed-through V'_{r31}. Roughly stated, at least 50% of the design time for electronic circuit techniques goes toward dealing with the problem of compensation. Thus in complex circuits, the connection between the function parameter gm and the various disturbance parameters requires more and more modifications in circuit variations. If a VCCS without disturbance parameters was available for users, the huge variety of electronic circuit techniques could be reduced.

THE "IDEAL" CURRENT SOURCE

The macro element operational transconductance amplifier (OTA) and operational amplifier (OA) contain circuit parts for reducing the previously mentioned disturbance parameters. The feedback operation necessary with these amplifiers— i.e. the application of a control loop with its unavoidable delay time (phase delays)— causes significantly reduced time and frequency domain performance compared to the VCCS. Straight-forward amplifiers are thus more wide-banded than feedback amplifiers. An operational amplifier OA, as shown in Figure 3, consists of the series connection of an OTA with a buffer B. The OTA is a voltage-controlled current source VCCS, in which the electrode 2 can be used "only" as a high-impedance input. Because of this distinction, the OTA can only be used with an external feedback loop. In contrast to conventional operational amplifiers with voltage feedback as shown in Figure 3, the current-feedback OA contains an OTA with low-impedance input and output 2—i.e. the previously represented "ideal" VCCS. The Diamond circuit, illustrated in Figure 4, opens up the possibility of implementing the quasi-ideal VCCS [2]. In the ideal case, in which NPN and PNP transistors are identical, the disturbance parameters V_{0FF1}', V_{OFF3}', I_{BIAS1}', and I_{BIAS3}' disappear. But in real circuits, of course, this is not the case. The remaining parameter values are, however, much smaller in comparison with a conventional VCCS (compare VCCS with DCS in Figure 1 and Table I). In the modulation range being examined, from $I_3 = \pm10mA$, the transconductance varies from 120 to 160mA/V as opposed to 0 to 350mA/V. This means that the improved VCCS (designated DCS from now on) causes a reduction in signal distortion.

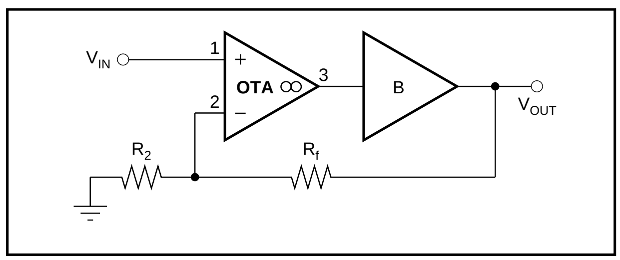

FIGURE 3. Operational Amplifiers as Series Connection Between OTA and Buffer.

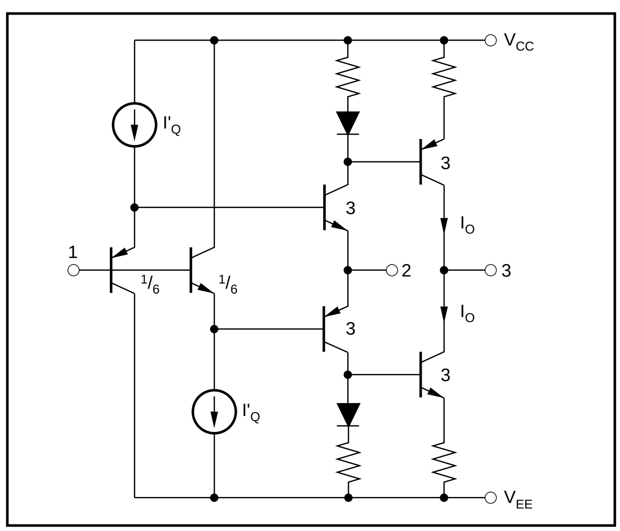

FIGURE 4. VCCS with Diamond Structure.

PROGRAMMABLE TRANSCONDUCTANCE

Conventional VCCSs allow the transconductance to be adjusted depending upon the quiescent current. In the DCS, the transconductance is adjusted primarily with the current sources I'_Q (see Figure 4). For this adjustment, one effective method is to create a current source control (Figure 5).

Using the resistor R_Q, the quiescent current I'_Q or I_Q and thus the transconductance gm can be fixed. The temperature function of gm (due to $V_T = f(T)$) is compensated for by corresponding variations of I_Q. For $R_Q \rightarrow \infty$, $I_Q \rightarrow 0$ and gm $\rightarrow 0$, and VCCS is switched off. In contrast to the conventional VCCS, the DCS functions in two quadrants at the input and in four at the output. In the VCCS, the transconductance is fixed by the choice of DC points within the usable modulation range, while the transconductance in the DCS is largely independent of the modulation and can be adjusted with the external resistor R_Q.

$gm = dI_3/dV_{12}$ is negative for all VCCSs. In contrast, the transconductance $gm = dI_3/dV_{12}$ of the DCS is positive. As previously mentioned, the following standard applications are available for the DCS (Figure 7): Buffer (B), Current-Feedback Transconductance Buffer (TB), Transconductance Amplifier (TA), Direct-Feedback Transconductance Amplifier (TD), Current-Feedback OA (TCC), and Voltage-Feedback OA (TCV).

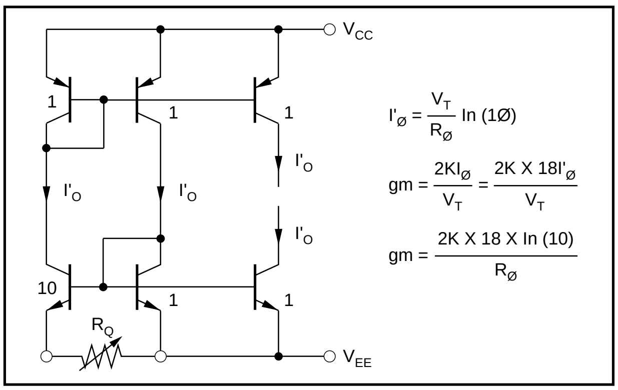

FIGURE 5. Current Source Control with Adjustable Bias Current.

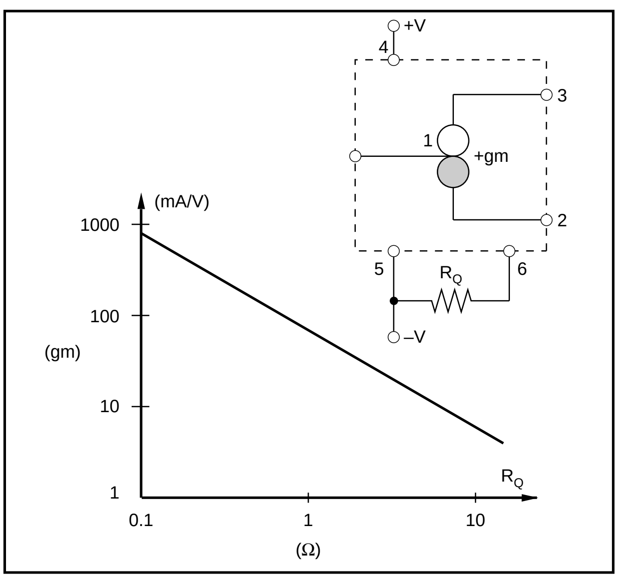

FIGURE 6. The Relations gm = f(R_Q) and Block Diagram of the DCS.

OUTLOOK

To characterize typical dynamic coefficient values (Table II), a developed DCS including a SOI package was simulated in the circuit shown in Figure 8. Burr-Brown brought this DCS onto the market as OPA660.

LITERATURE

[1] Ross, D.G. et al; IEEE Journal of solid-state circuits 86, vol. 2, p. 331.

[2] Lehmann, K; Elektronik Industrie 89, vol. 5, p. 99. Strom-oder Spannungs-Gegenkopplung? (Current or Voltage Feedback? That's the question here.)

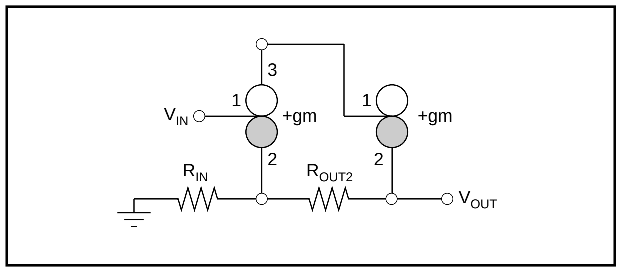

FIGURE 8. Circuit for Recording the Dynamic Characteristic of a TCC with DCS.

I_Q (mA)	0.1Vp-p f_{-3dB} (MHz)	6Vp-p f_{-3dB} (MHz)	4Vp-p SR (V/µs)	1.4Vp-o DG (%)	5MHz DP (Degrees)
2.4	400	330	2850	–0.07	–0.05
1.2	240	200	1750	–0.06	–0.06
0.6	140	100	800	–0.05	–0.10
0.3	80	55	420	–0.03	–0.19

TABLE II. Typical Dynamic Values of a TCC with DCS Corresponding to the Circuit in Figure 8.

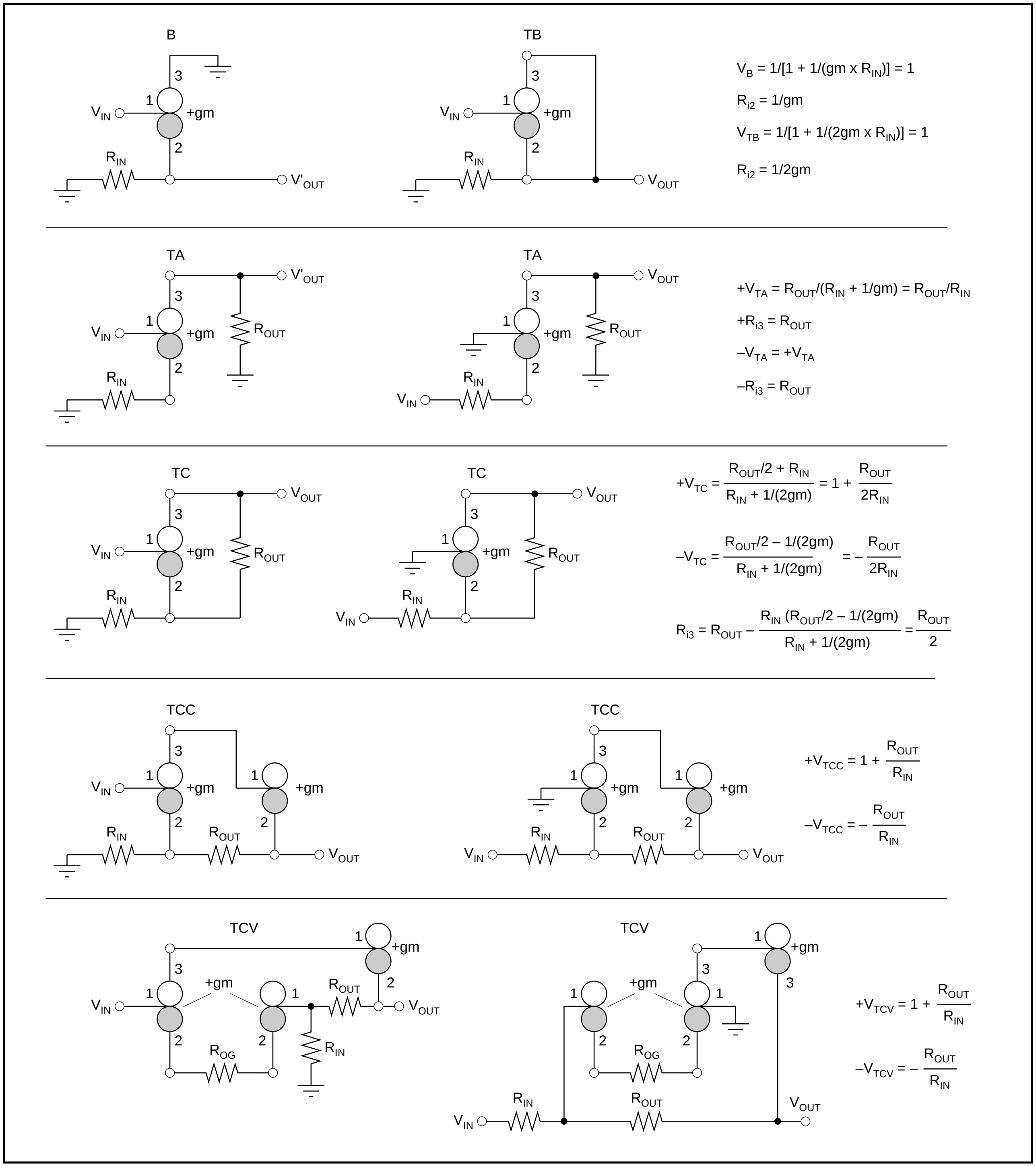

FIGURE 7. Standard Applications with the DCS.