Application of the CA3028 and Integrated-Circuit RF Amplifiers in the HF and VHF Ranges

Application Note | May 1998 | AN5337

Introduction

The CA3028A and CA3028B integrated circuits are single-stage differential amplifiers. Each circuit also contains a constant-current transistor and suitable biasing resistors. The circuits are primarily intended for service in communications systems operating at frequencies up to 100MHz with single power supplies. This Note provides technical data and recommended circuits for use of the CA3028A and CA3028B in the following applications:

- RF Amplifier
- Autodyne Converter
- IF Amplifier
- Limiter

In addition to the applications listed above, the CA3028A and CA3028B are suitable for use in a wide range of applications in DC, audio, and pulse amplifier service; they have been used as sense amplifiers, preamplifiers for low-level transducers, and DC differential amplifiers. The CA3028B, which features tight control of operating current, input offset voltage, and input bias and offset current, is recommended for those applications in which balance and operating conditions are important.

Circuit Description

The circuit diagram and terminal numbers for the CA3028A and CA3028B are shown in Figure 1. The circuit is basically a single-stage differential amplifier composed of transistors Q_1 and Q_2 driven from a constant-current source Q_3. A single-ended input may be connected to terminal 1 or terminal 5, or push-pull inputs to terminals 1 and 5. Each of these terminals must be provided with a biasing network. Care must be taken to insure that the bias voltages on terminals 1 and 5 are nearly equal when balanced operation is desired. This can only be achieved in practice by using a single voltage divider as shown in Figure 2A. Bias is first established on the base of one transistor, in this case Q_1, through terminal 1. The base of the second transistor, Q_2 in Figure 2A, is then connected to the first through a low-valued DC impedance. In Figure 2A, the inductive winding of the input transformer provides the low-resistance path. An RF choke or low-valued resistor may be used in place of transformer coupling, but caution must be exercised because even as little as 100Ω may cause serious unbalance in some applications. A single-ended output may be taken from terminal 6 or terminal 8, or push-pull outputs from terminals 6 and 8. In systems with a single power supply of up to 12V, terminal 7 is connected to the highest positive potential for maximum gain. Other operating points can be selected by application of a varying bias voltage (AGC) to Q_3.

The circuit diagrams in Figure 2 illustrate the flexibility of the CA3028A and CA3028B. Terminal connections are shown for a differential amplifier driven from a controlled constant-current source that has AGC capability, a cascode amplifier with constant-impedance or conventional AGC capability, a converter, a mixer, and an oscillator. The cascode mode of operation is recommended for applications that require higher gain. The differential mode is preferred when good limiting is required.

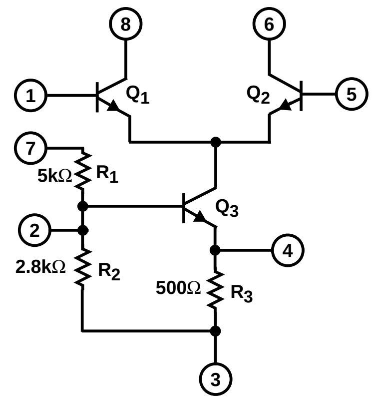


FIGURE 1. SCHEMATIC DIAGRAM AND TERMINAL NUMBERS FOR THE CA3028A, CA3028B

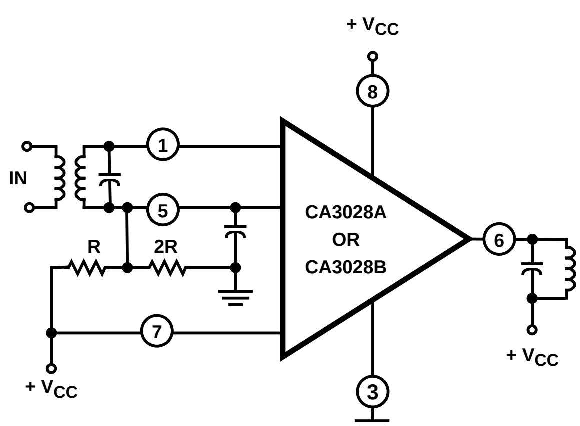


FIGURE 2A.

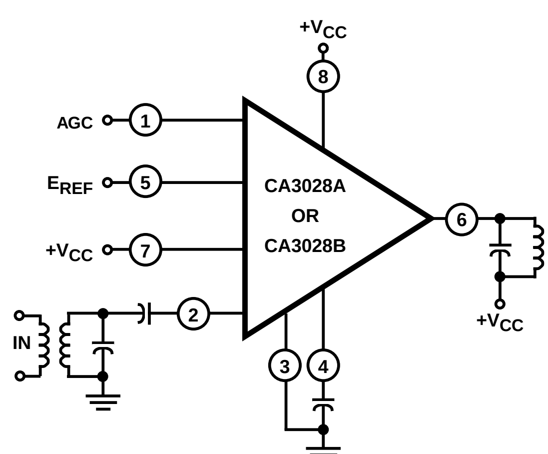


FIGURE 2B.

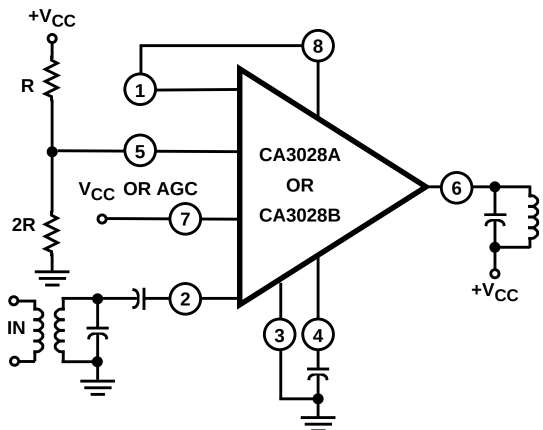


FIGURE 2C.

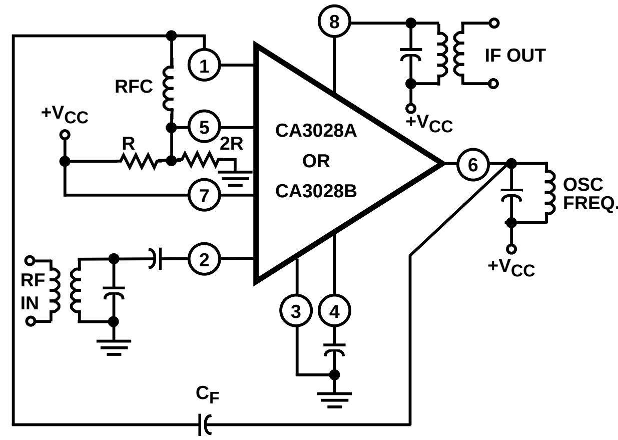


FIGURE 2D.

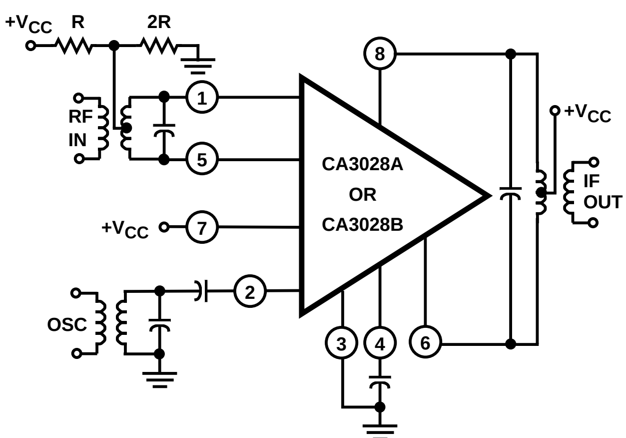


FIGURE 2E.

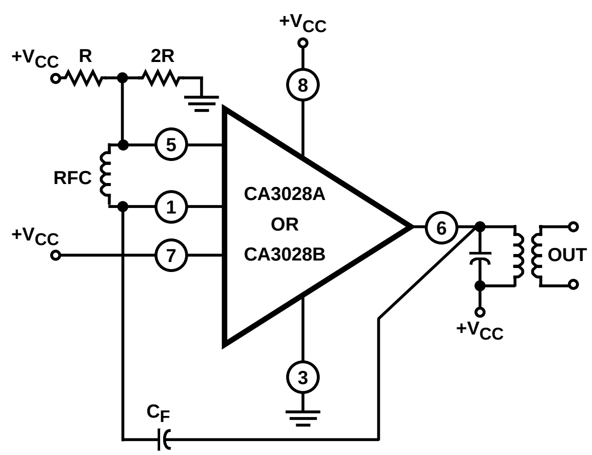


FIGURE 2F.

FIGURE 2. CONNECTIONS FOR THE CA3028A AND CA3028B FOR USE AS (A) A BALANCED DIFFERENTIAL AMPLIFIER WITH A CONTROLLED CONSTANT-CURRENT-SOURCE DRIVE AND AGC CAPABILITY; (B) A CASCODE AMPLIFIER WITH A CONSTANT-IMPEDANCE AGC CAPABILITY; (C) A CASCODE AMPLIFIER WITH CONVENTIONAL AGC CAPABILITY; (D) A CONVERTER; (E) A MIXER; (F) AN OSCILLATOR

Operating Modes

The CA3028A and CA3028B integrated-circuit RF amplifiers can be operated in either the differential mode or the cascode mode. Applications using the differential mode are distinguished by high input impedance, good gain-control characteristics, large input-signal-handling capability, and good limiting.

For ease of design of systems using the CA3028A and CA3028B, admittance or "y" parameters are shown in Figure 3 for the differential mode and in Figure 4 for the cascode mode. It should be noted that the y parameters of the more complex differential and cascode amplifier stages differ from those of simple common-emitter transistor stages.

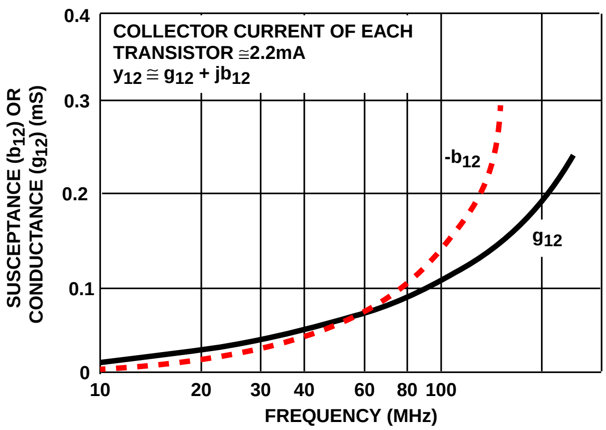


FIGURE 3A. REVERSE TRANSADMITTANCE (Y_{12})

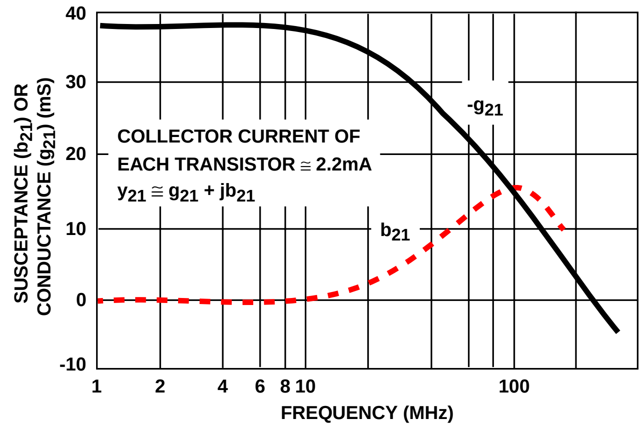


FIGURE 3B. FORWARD TRANSADMITTANCE (Y_{21})

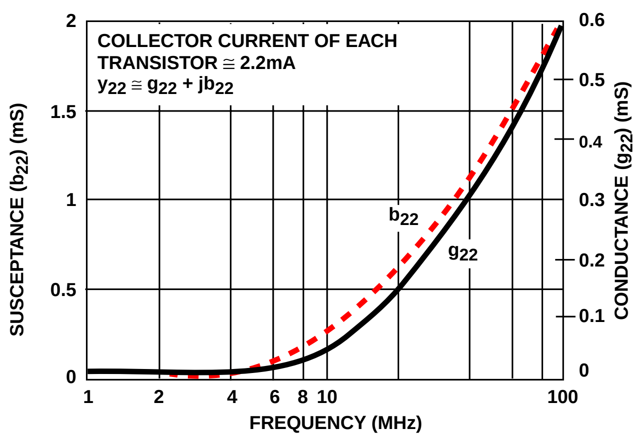


FIGURE 3C. OUTPUT ADMITTANCE (Y_{22})

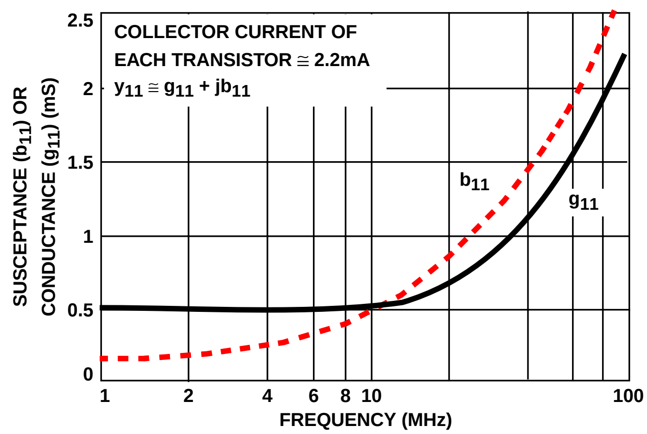


FIGURE 3D. INPUT ADMITTANCE (Y_{11})

FIGURE 3. Y PARAMETERS OF THE CA3028A AND CA3028B IN THE DIFFERENTIAL-AMPLIFIER CONNECTION

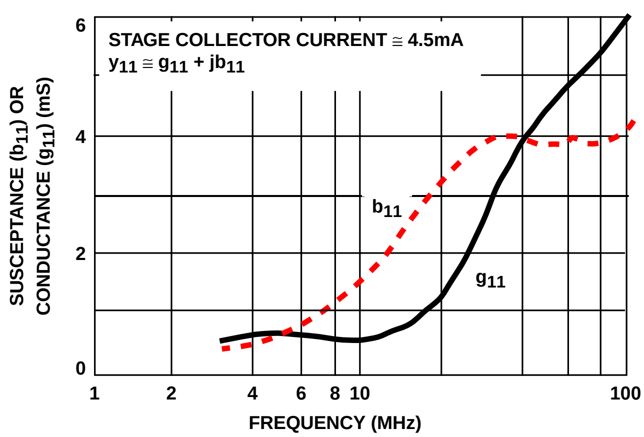


FIGURE 4A. INPUT ADMITTANCE (Y_{11})

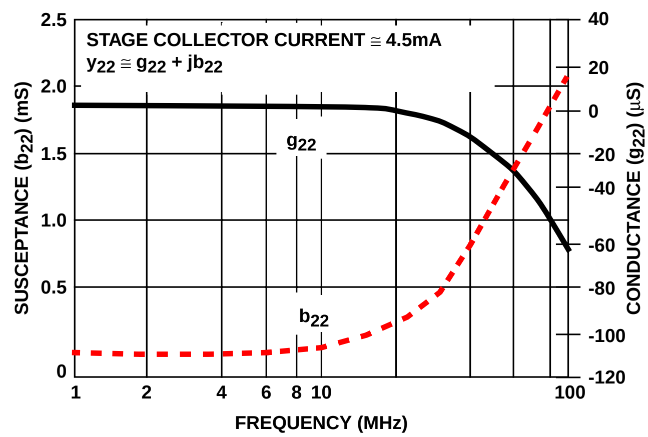


FIGURE 4B. OUTPUT ADMITTANCE (Y_{22})

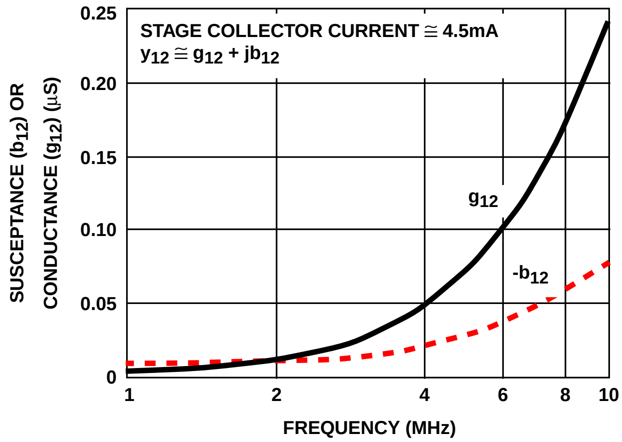


FIGURE 4C. REVERSE TRANSADMITTANCE (Y_{12})

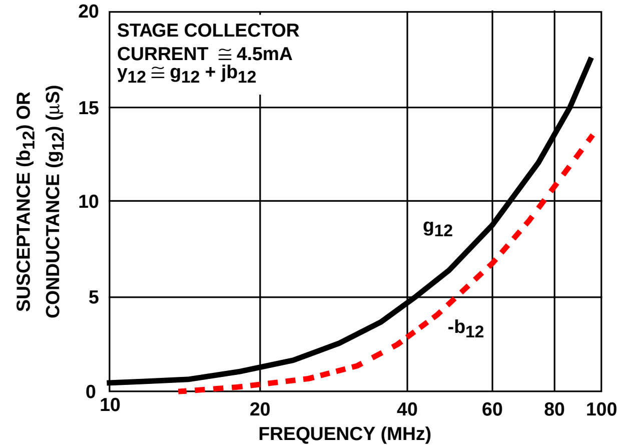


FIGURE 4D. REVERSE TRANSADMITTANCE (Y_{12})

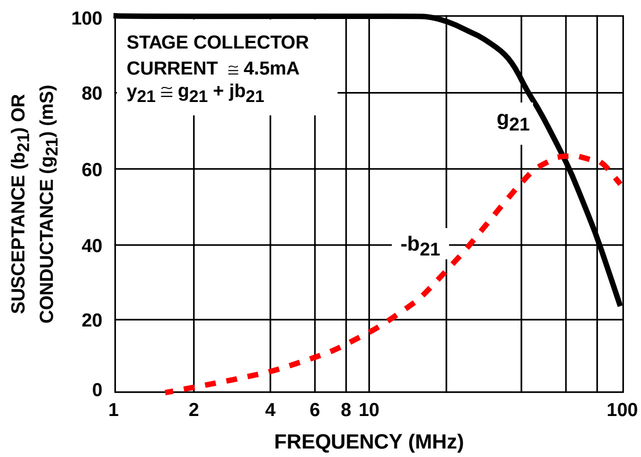


FIGURE 4E. FORWARD TRANSADMITTANCE (Y_{21})

FIGURE 4. Y PARAMETERS OF THE CA3028A AND CA3028B IN THE CASCODE CONNECTION

For quick reference, values for input and output parallel RC networks and transconductance values are listed in Table 1 for the differential amplifier and in Table 2 for the cascode amplifier.

Although the reverse transfer admittance y_{12} of the CA3028A or CA3028B is low for either cascode or differential operation, circuit-layout-induced instability can occur in high-gain amplifiers. Circuit layout is of paramount importance in both modes because undesirable coupling admittances can be much greater than the CA3028A or CA3028B admittances. Attention to layout and shielding is imperative if proper advantage is to be taken of the low feedback of the CA3028A and CA3028B.

TABLE 1. CASCODE AMPLIFIER SUMMARY

FREQUENCY (MHz)	INPUT PARALLEL RC NETWORK		OUTPUT PARALLEL RC NETWORK		TRANSCONDUCTANCE
	R_{IN} (Ω)	C_{IN} (pF)	R_{OUT} (Ω)	C_{OUT} (pF)	g_m (mS)
10.7	900	22	-1.67×10^6	3.1	100
100	170	6.3	-5×10^5	3.5	14

TABLE 2. MAXIMUM PERMISSIBLE LOAD RESISTANCES FOR NO SATURATION

V_{CC} (V)	$I_{C1} + I_{C2}$ (mA)	MAXIMUM TUNED LOAD ($R_L = 2V_{CC}/(I_{C1} + I_{C2})$) (Ω)	MAXIMUM RESISTIVE LOAD (Ω) ($V_{CC}/(I_{C1} + I_{C2})$)
+9	5.0	3.6K	1.8K
+12	6.8	3.5K	1.7K

Differential Amplifier

The differential amplifier shown in Figure 2A is designed for operation at 10.7MHz and 100MHz. Because the amplifier consists essentially of a common-collector stage driving a common-base stage, the input admittance y_{11}, the output admittance y_{22}, and the forward transfer admittance y_{22} are decreased by a factor of two. The reverse transfer admittance y_{12} is typically 140 times lower than that of a single common-emitter transistor at 10.7MHz, and 10 times lower at 100MHz. As a result, the CA3028A and CA3028B can be aligned easily in IF strips without need for neutralization.

The transfer characteristic in Figure 5A shows the excellent limiting capabilities of the CA3028A and CA3028B differential amplifiers. This limiting performance is achieved because the constant-current transistor Q_3 limits the circuit operating current so that the collectors of the differential-pair transistors Q_1 and Q_2 do not saturate. Table 3 shows the maximum permissible load resistances for non-saturating operation when single supply voltages of 9V and 12V are used.

When linear operation over a wide input-voltage range is imperative, AGC voltage may be applied to the constant-current source Q_3 at terminal 7. Gain-control capabilities are 60dB at 10.7MHz and 46dB at 100MHz, as shown in Figure 5B. Figure 5C shows curves of power gain and noise figure as a function of AGC voltage. The combination of an optimum noise figure of 5.5dB and a power gain of 15dB at 100MHz makes this circuit suitable for use as an RF amplifier in the commercial FM band.

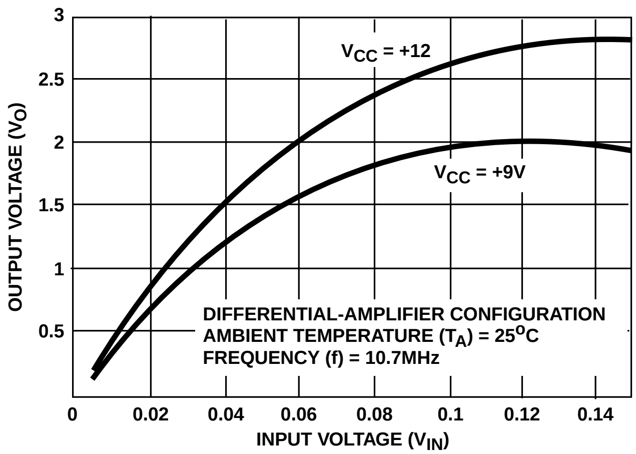


FIGURE 5A.

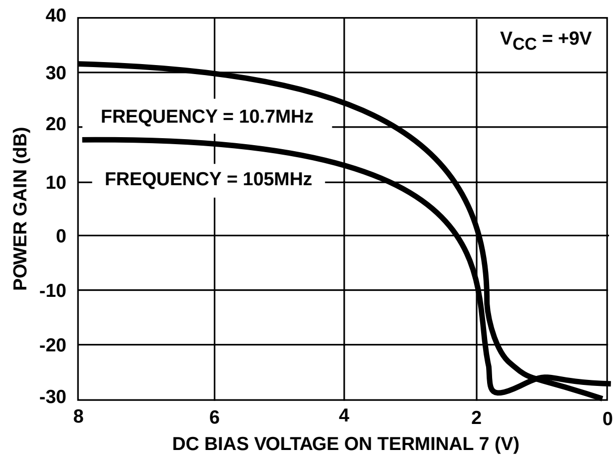


FIGURE 5B.

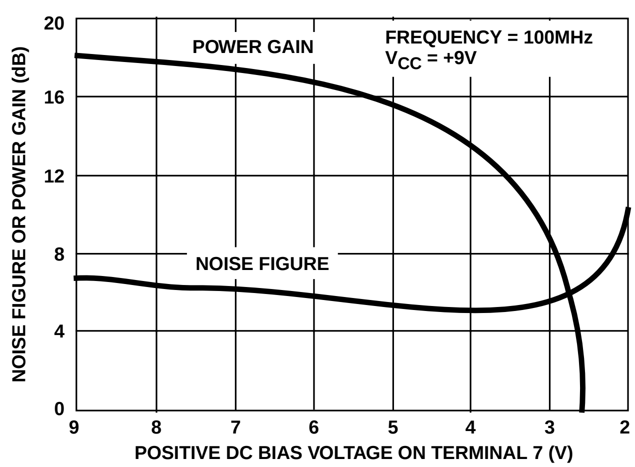


FIGURE 5C.

FIGURE 5. CHARACTERISTICS OF THE CA3028A AND CA3028B IN THE DIFFERENTIAL-AMPLIFIER CONNECTION: 5A - 10.7MHz TRANSFER CHARACTERISTICS; 5B - AGC CAPABILITIES; 5C - POWER GAIN AS A FUNCTION OF NOISE FIGURE

Cascode Amplifier

When the CA3028A or CA3028B is used in the cascode configuration for RF-amplifier circuits, a common-emitter stage drives a common-base stage. The input admittance y_{11} is essentially that of a common-emitter stage, and the forward transfer admittance y_{21} is that of a common-emitter stage times the common-base alpha. Because of the high-impedance drive source for the common-base stage, the output admittance y_{22} is quite low (0.6µS) at low frequencies. The reverse transfer admittance y_{12} for the cascode circuit is 900 times less than that for a single-stage common-emitter at 10.7MHz, and 35 times less at 100MHz. As in the differential amplifier, ease in tuning is obtained without need for neutralization.

The transfer characteristic in Figure 6 shows the suitability of the cascode configuration for AGC takeoff for FM front-end controls.

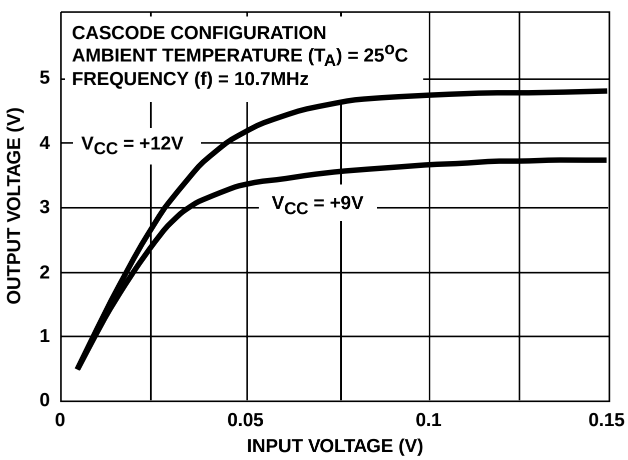


FIGURE 6. TRANSFER CHARACTERISTICS (CASCODE CONFIGURATION)

Applications

The typical applications described below illustrate the use of the CA3028A and CA3028B integrated-circuit RF amplifiers in both the differential and the cascode modes.

10.7MHz Cascode IF Amplifier

Figure 7 shows an FM IF strip in which the CA3028A or CA3028B is used in a high-gain, high-performance cascode configuration in conjunction with a CA3012 integrated-circuit wide-band amplifier. The CA3012 is used in the last stage because of the high gain of 74dB input to the 400Ω-load ratio-detector transformer T_4. An input of approximately 400µV is required at the base of the CA3012 for -3dB below full limiting. An impedance-transfer device and filter must be connected between the CA3012 base (terminal 1) and the output of the CA3028A or CA3028B (terminal 6). The insertion loss of this filter should be kept near 6dB (1:2 ratio of loaded to unloaded Q) so that all possible gain can be realized up to the CA3012 base. In addition to this insertion loss, a voltage step-down loss of 5.8dB in the interstage filter is unavoidable. Therefore, the total voltage loss is approximately 9dB to 14dB, and an output of 1500 to 2000µV must be available from the CA3028A or CA3028B to provide the required 400µV input to the CA3012.

The voltage gain of the CA3028A or CA3028B into a 3000Ω load is determined as follows:

$$V_G = \frac{-y_{21}}{y_{22} + y_L} = \frac{100 \times 10^{-3}}{0.33 \times 10^{-3}} = 300 = 49\text{dB} \qquad \text{(EQ. 1)}$$

This calculation indicated a sensitivity of 6.6µV at the CA3028A or CA3028B base (terminal 2). This value cannot be realized, however, because the CA3012 limits on noise peaks so that the gain figure is reduced.

A sensitivity of 7.5µV was realized in the design shown in Figure 7. The filter approach with high-gain integrated-circuit chips differs from that for single, cascaded transistor stages in that lumped selectivity is required rather than distributed selectivity.

Special care must be exercised when second-channel attenuation in the order of 45dB is required. Selectivity is then proportioned as follows:

Interstage filter: double-tuned 220kHz at -3dB; coefficient of critical coupling, 0.7; voltage loss, 8dB

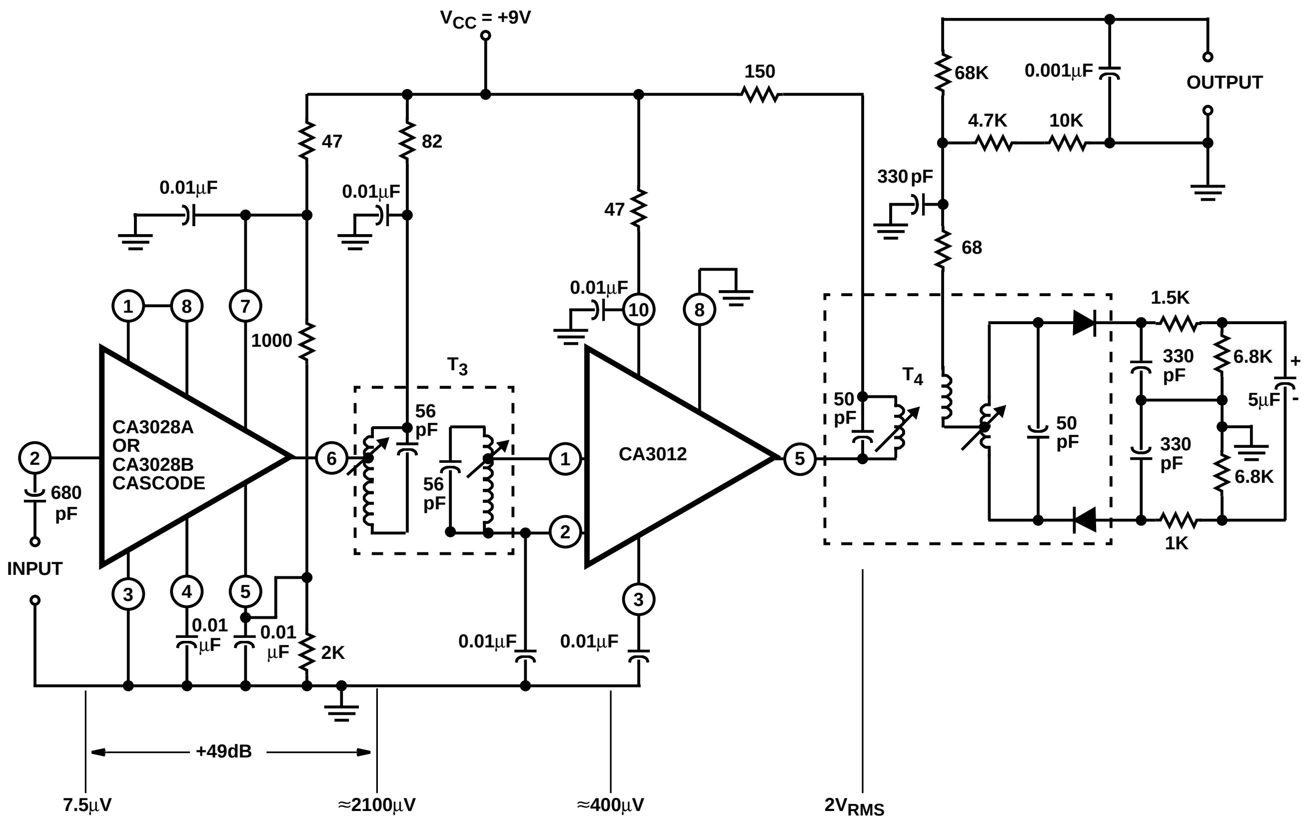
Converter filter: triple-tuned, 220kHz at -3dB; coefficient of critical coupling, 0.8; voltage loss, about 28dB

Because of input limiting in the CA3012, the interstage filter exhibits a somewhat wider bandwidth than the 220kHz indicated. Therefore, a coefficient of critical coupling near 0.8 is realized, which is optimum for minimum deviation from constant time delay. The triple-tuned converter filter alone provides second-channel attenuation of 30dB to 33dB, while the interstage filter contributes 8dB to 10dB. The filters described meet requirements of both performance and economy.

The large collector swing that can be obtained in cascode operation of the CA3028A or CA3028B makes it desirable to take the AGC voltage from the collector or “hot” end of the IF transformer for front-end gain control. The cascode stage then operates primarily in its linear region, and excellent selectivity (40dB) is maintained even for large signal inputs of approximately 0.4V. Front-end gain reduction is between 40dB and 50dB.

10.7MHz IF Strip Using Two CA3028A or CA3028B Circuits

The 10.7MHz IF strip shown in Figure 8 uses two CA3028A or CA3028B integrated circuits to provide less overall gain than the circuit of Figure 7. The first integrated circuit is connected as a cascode amplifier and yields voltage gain of 50dB; the second integrated circuit is connected as a differential amplifier and yields voltage gain of 42dB.



T_3: INTERSTAGE TRANSFORMER TRW #22486 OR EQUIVALENT

T_4: RATIO DETECTOR TRW #22516 OR EQUIVALENT

AUDIO OUTPUT: 155mV$_{RMS}$ FOR 7.5µV ± 75kHz INPUT 3dB BELOW KNEE OF TRANSFER CHARACTERISTIC

FIGURE 7. 10.7MHz IF AMPLIFIER USING A CA3028A OR CA3028B IN THE CASCODE MODE

When a practical interstage transformer having a voltage insertion loss of 9dB is used, overall gain is 83dB and the sensitivity at the base of the first integrated circuit is 140µV. A less sophisticated converter filter (double-tuned) could be employed at the expense of about 26dB of second-channel attenuation. If the voltage insertion loss of the converter filter is assumed to be 18dB and the front-end voltage gain (antenna to mixer collector) is 50dB, this receiver would have an IHFM sensitivity of approximately 8µV.

(IHFM - Institute of High-Fidelity Manufacturers)

10.7MHz Differential-Amplifier IF Strip

Figure 9 shows a 10.7MHz medium-gain IF strip consisting of a CA3028A or CA3028B connected as a differential amplifier and a CA3012 wide-band amplifier. As in the circuit shown in Figure 7, an input of approximately 1500µV is required to the inter stage filter. The differential-mode voltage gain of the CA3028A or CA3028B into a 3000Ω load is determined as follows:

$$V_G = \frac{-y_{21}}{y_{22} + y_L} = \frac{35 \times 10^{-3}}{0.38 \times 10^{-3}} = 92.5 = 39.3\text{dB} \qquad \text{(EQ. 2)}$$

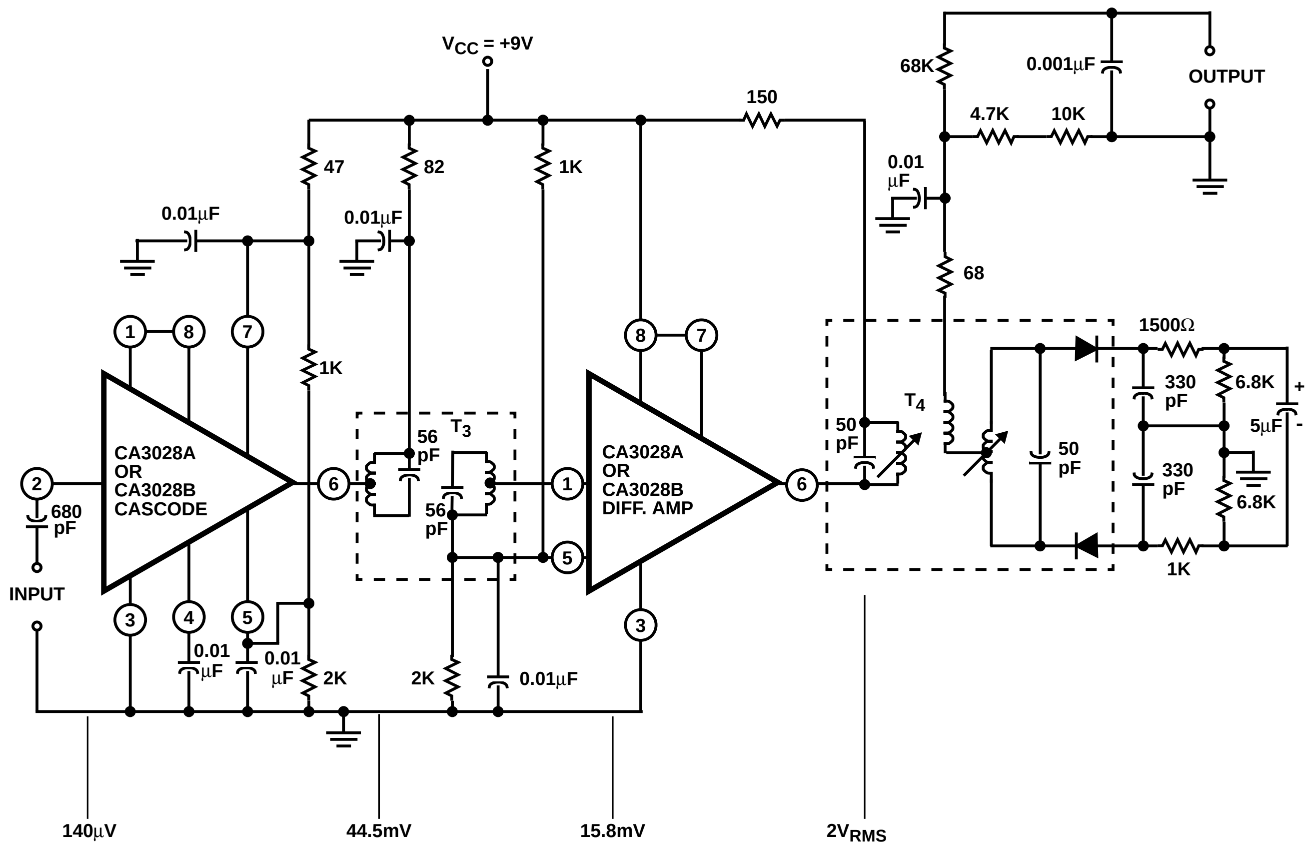
This voltage gain requires that an input of approximately 15mV be available at the base of the CA3028A or CA3028B differential amplifier.

Even if a triple-tuned filter having a voltage insertion loss of 28dB is used in a low-gain front end, a receiver having an IHFM sensitivity of 5µV results. If 26dB second-channel attenuation is permissible, a 3µV-sensitivity IHFM receiver can be realized.

88MHz to 108MHz FM Front End

Figure 10 illustrates the use of the CA3028A or CA3028B as an RF amplifier and a converter in an 88 to 108MHz FM front end. For best noise performance, the differential mode is used and the base of the constant-current source Q_3 is biased for a power gain of 15dB. The RF amplifier input circuit is adjusted for an insertion loss of 2dB to keep the noise figure of the front end low. Because the insertion loss of the input transformer adds directly to the integrated-circuit noise figure of 5.5dB, the noise figure for the front end alone is 7.5dB, as compared to noise figures of about 6dB for commercial FM tuners.

Although a single-tuned circuit is shown between the collector of the RF-amplifier stage and the base of the converter stage, a double-tuned circuit is preferred to reduce spurious response of the converter. If the double-tuned circuit is critically coupled for the same 3dB bandwidth as the single-tuned circuit, the insertion loss remains the same.



T_3: INTERSTAGE TRANSFORMER TRW #22486 OR EQUIVALENT

T_4: RATIO DETECTOR TRW #22516 OR EQUIVALENT

AUDIO OUTPUT: 155mV$_{RMS}$ FOR 140µV ± 75kHz INPUT 3dB BELOW KNEE OF TRANSFER CHARACTERISTIC

FIGURE 8. 10.7MHz IF STRIP USING TWO CA3028A OR CA3028B INTEGRATED CIRCUITS

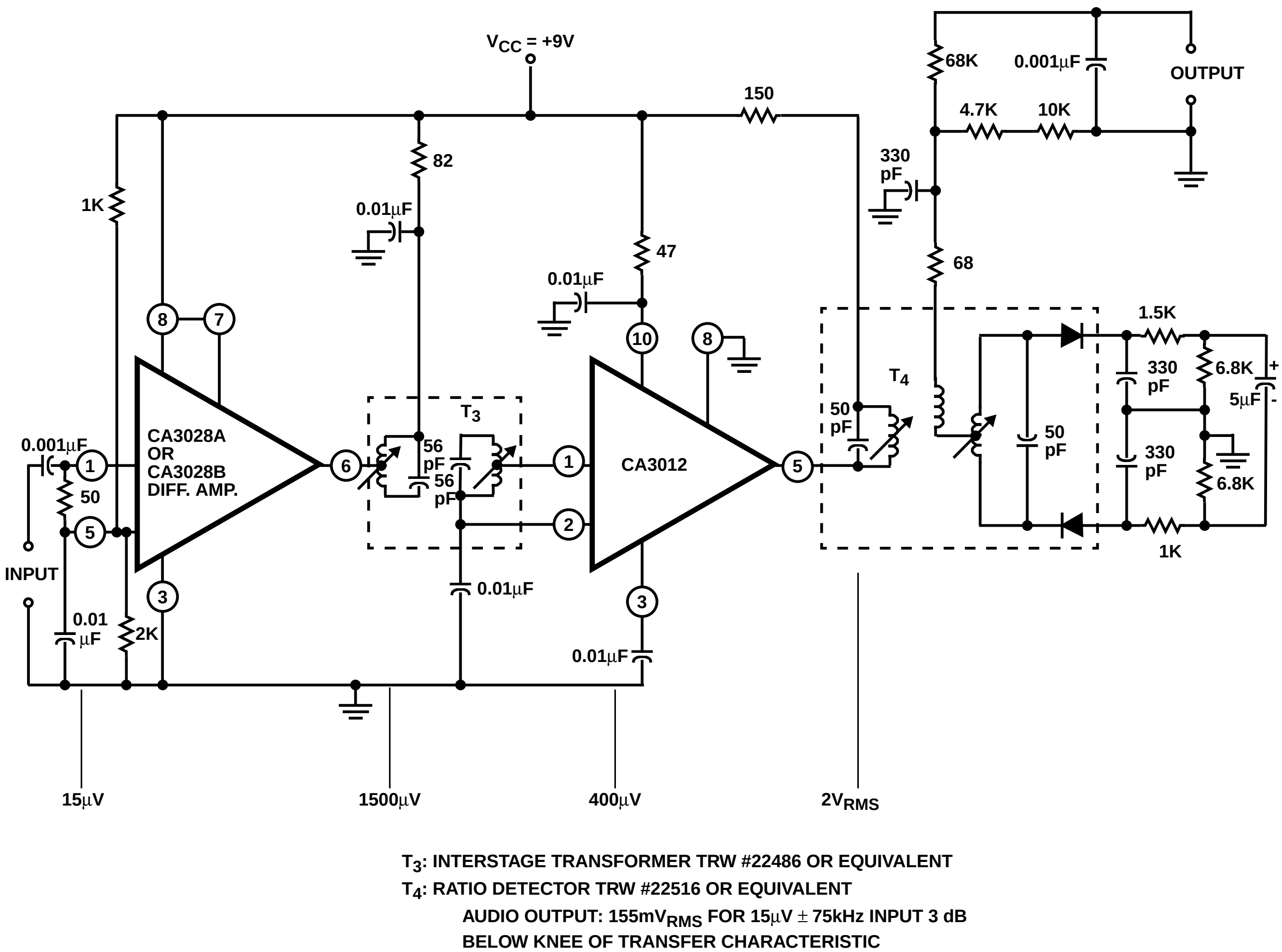


FIGURE 9. 10.7MHz IF STRIP USING A CA3028A OR CA3028B IN THE DIFFERENTIAL MODE

The collector of the RF stage is tapped down on the interstage coil at approximately 1500Ω, and the base of the converter stage at 150Ω. RF voltage gain is computed as follows:

Antenna to base	0dB
Base to collector	22dB
Voltage insertion loss of interstage coil	-13dB
Net RF voltage gain	9dB

If an IF converter transformer having an impedance of 10,000Ω is used, the calculated voltage conversion gain is:

$$V_{GC} = \frac{-y_{21}}{y_{22} + y_L} = 112 = 41.3\text{dB} \quad \text{(EQ. 3)}$$

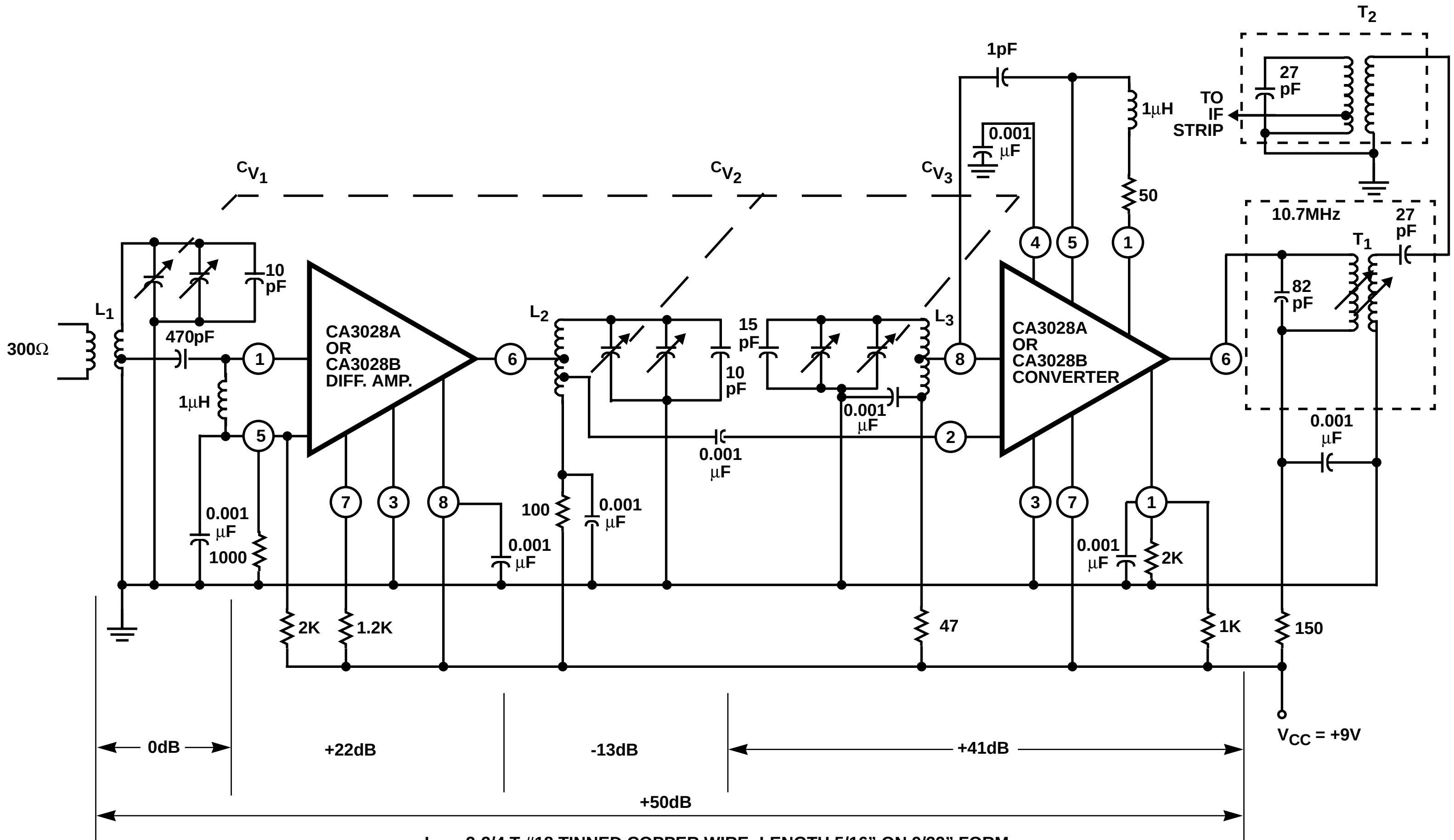
Measured gain into the collector of the converter is 42dB. The measured voltage gain of the RF amplifier and converter into a 10,000Ω load is 52dB; calculated gain is 50dB. When the converter is tuned for the commercial FM band (88MHz to 108MHz), the following parameters apply:

Input resistance (R_{IN})	170Ω
Input capacitance (C_{IN})	6.3pF
Output resistance (R_{OUT})	80kΩ
Output capacitance (C_{OUT})	3.5pF
Conversion transconductance	13mS

The RF amplifier and converter shown in Figure 10 were combined with the IF amplifier shown in Figure 7, and the following performance data were measured at 100MHz:

30dB (S + N)/N IHFM Sensitivity	3µV
Image Rejection	46dB

Receiver noise figure is the limiting factor that permits a sensitivity of only 3µV to be realized.



L_1 : 3-3/4 T #18 TINNED COPPER WIRE; LENGTH 5/16” ON 9/32” FORM; TAPPED AT 1-3/4 T; PRIMARY - 2 TURNS #30 SE

L_2 : 3-3/4 T #18 TINNED COPPER WIRE; LENGTH 5/16” ON 9/32” FORM; TAPPED AT 6 2-1/4 T, A 3/4T

$C_{V1\text{-}3}$: VARIABLE Δ C $\approx$ 15pF

T_1 : MIXER TRANSFORMER TRW #22484 OR EQUIVALENT

T_2 : INPUT TRANSFORMER TRW #22485 OR EQUIVALENT

L_3 : 3-1/2T #18 TINNED COPPER WIRE; WINDING LENGTH 5/16” ON 9/32” FORM

FIGURE 10. 88MHz to 108MHz FM FRONT END