TDA7000 for narrowband FM reception   AN193

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INTRODUCTION

Today's cordless telephone sets make use of duplex communication with carrier frequencies of about 1.7MHz and 49MHz.

- In the base unit incoming telephone information is frequency-modulated on a 1.7MHz carrier.

- This 1.7MHz signal is radiated via the AC mains line of the base unit.

- The remote unit receives this signal via a ferrite bar antenna.

- The remote unit transmits the call signals and speech information from the user at 49MHz via a telescopic antenna.

- The base unit receives this 49MHz FM-modulated signal via a telescopic aerial.

channel at, e.g., 30kHz, must be 50dB, and the bandwidth of the channel must be 6-10kHz for good reception. Therefore, an IF frequency of 455kHz is chosen. Since at this frequency there are ceramic filters with a bandwidth of 9kHz (AM filters), the 1.7MHz is mixed down to 455kHz with an oscillator frequency of 2.155MHz. Now there is an image reception at 2.61MHz. To suppress this image sufficiently, there must be at least two RF filter sections at the input of the receiver.

Today's Remote Unit Receivers

In cordless telephone sets, a normal superheterodyne receiver is used for the 1.7MHz handset. The suppression of the adjacent

The ceramic IF filter with its subharmonics is bad for far-off selectivity, so there must be an extra LC filter added between the mixer output and the ceramic filter.

After the selectivity there is a hard limiter for AGC function and suppression of AM.

Next, there is an FM detector which must be accurate because it must detect a swing of ± 2.5kHz at 455kHz; therefore, it must be tuned.

Figure 1 shows the block diagram which fulfills this principal. The total number of alignment points of this receiver is then 5:
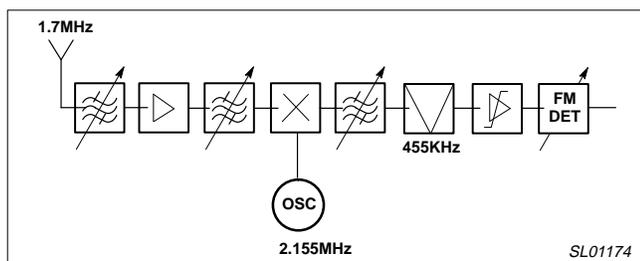

Figure 1. Remote-unit Receiver: 1..7MHz

2 RF filters
1 Oscillator
1 IF filter
1 FM detector

5 Alignments

A Remote Unit Receiver With TDA7000

The remote unit receiver (see Figure 2) has as its main component the IC TDA7000, which contains mixer, oscillator, IF amplifiers, a demodulator, and squelch functions.

To avoid expensive filtering (and expensive filter-adjustments) in RF, IF, and demodulator stages, the TDA7000 mixes the incoming signal to such a low IF frequency that filtering can be realized by active RC filters, in which the active part and the Rs are integrated.

To select the incoming frequency, only one tuned circuit is necessary: the oscillator tank circuit. The frequency of this circuit can be set by a crystal.

IMAGE RECEPTION

For today's concept, a number of expensive components are necessary to suppress the image sufficiently. The suppression of the image is very important because the signal at the image can be much larger than the wanted signal and there is no correlation between the image and the wanted signal.

In a concept with 455kHz IF frequency, the 1.7MHz receiver has image reception at 2.155MHz. In the TDA7000 receiver, the IF frequency is set at 5kHz. Then the 1.7MHz receiver (with 1.695MHz oscillator frequency) has image reception at 1.69MHz, which is at

10kHz from the required frequency (see Figure 3).

An IF frequency of 5kHz has been chosen because:

- this frequency is so low, there will be no neighboring channel reception at the image frequency.

- this frequency is not so low that at maximum deviation (maximum modulation) distortion could occur (folding distortion, caused by the higher-order bessel functions)

- this frequency gives the opportunity to obtain the required neighboring channel suppression with minimum components in the IF selectivity.

## CIRCUIT DESCRIPTION (SEE FIGURE 2)

When a remote unit is at "power-on" in the "standby" position, it is ready to receive a "bell signal". A bell signal coming through the telephone line will set the base unit in the mode of transmitting a 1.7MHz signal, modulated with, e.g., 0.75kHz with ± 3kHz deviation.

The ferrite antenna of the remote unit receives this signal and feeds it to the mixer, where it is converted into a 5kHz IF signal.

Before the RF signal enters the mixer (at Pins 13 and 14) it passes RF selectivity, taking care of good suppression of unwanted signals from, e.g., TV or radio broadcast frequencies. The IF signal from the mixer output passes IF selectivity (Pins 7 to 12) and the IF amplifier/limiter (Pin 15), from which the output is supplied to a quadrature demodulator (Pin 17). Due to the low IF frequency, cheap capacitors can be used for both IF selectivity and the phase shift for the quadrature demodulator.

The AF output of the demodulator (Pin 4) is fed to the AF filter and AF amplifier NE5535.

Figure 2.

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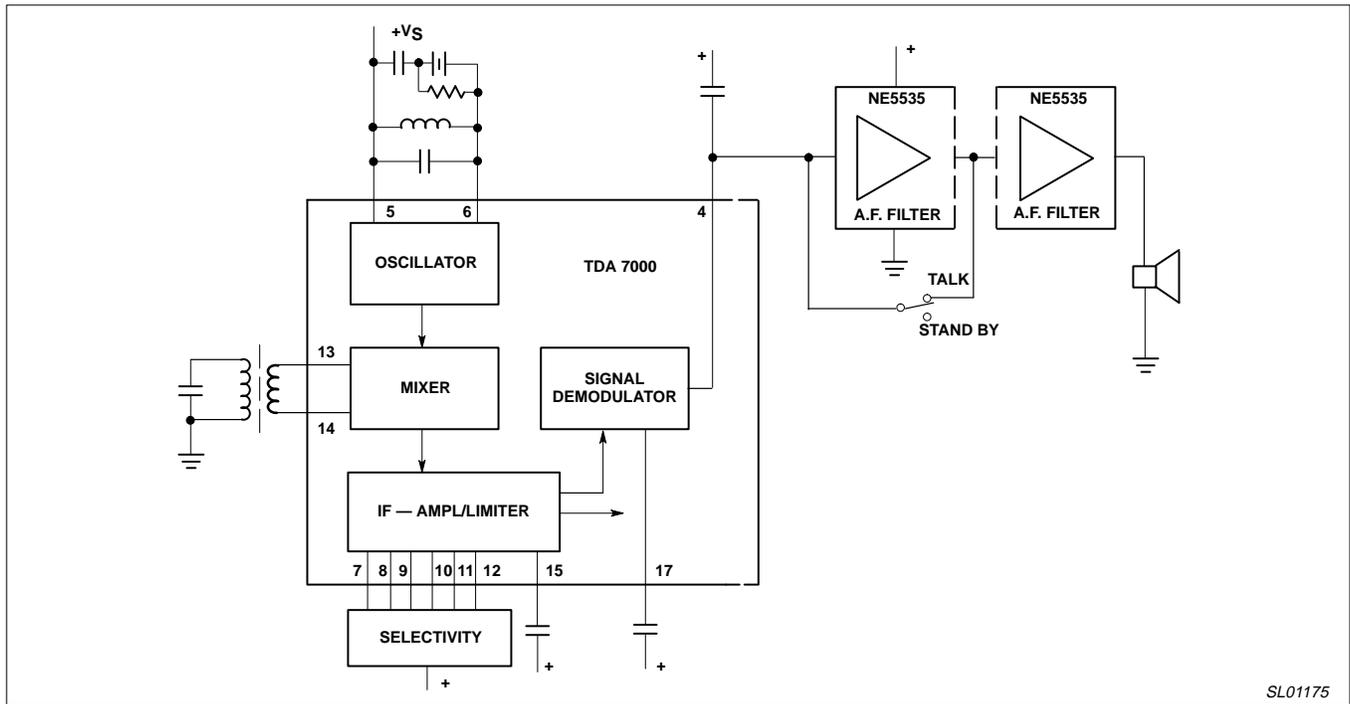
The RF Input Circuit

As the image reception is an in-channel problem, solved by the choice of IF frequency and IF selectivity, the RF input filter is only required for stopband selectivity (a far-off selectivity to suppress unwanted large signals from, e.g., radio broadcast transmitters).

In a remote unit receiver at 1.7MHz, this filter is at the ferrite rod. Figure 4 shows the bandpass behavior of such a filter at 1.7MHz.

The Mixer

The mixer conversion gain depends on the level of the oscillator voltage as shown in Figure 5, so the required oscillator voltage at Pin 6 is 200mV$_{RMS}$.

The Oscillator

To obtain the required frequency stability in a cordless telephone set, where adjacent channels are at 20 or 30kHz, crystal oscillators are commonly used.

The crystal oscillator circuits usable for this kind of application always need an LC-tuned resonant circuit to suppress the other modes of the crystal. In this type of oscillator (see Figure 6 as an example) the crystal is in the feedback line of the oscillator amplifier. Integration of such an amplifier should give a 2-pin oscillator.

The TDA7000 contains a 1-pin oscillator. An amplifier with current output develops a voltage across the load impedance. Voltage feedback is internal to the IC.

**Figure 3.**

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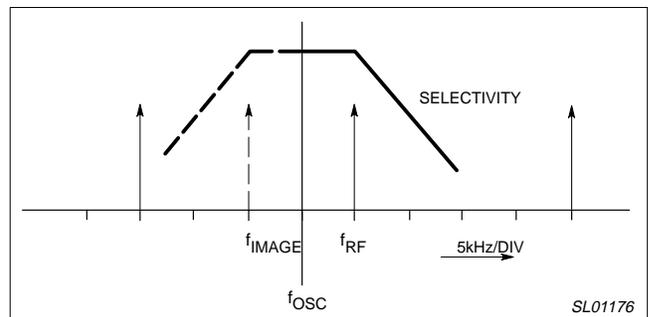
TDA7000 for narrowband FM reception

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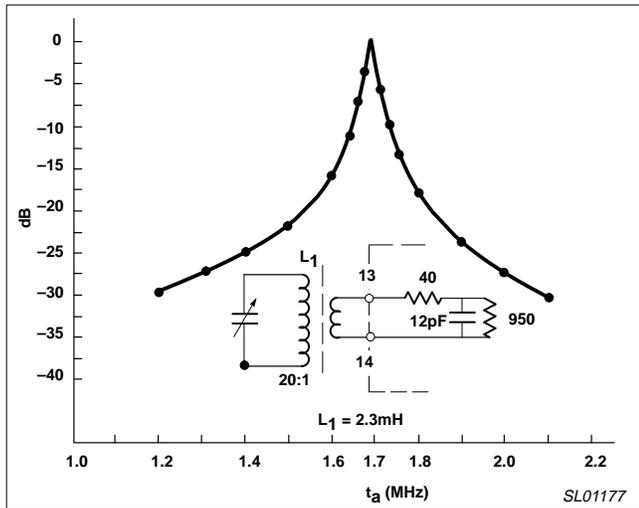
Figure 4.
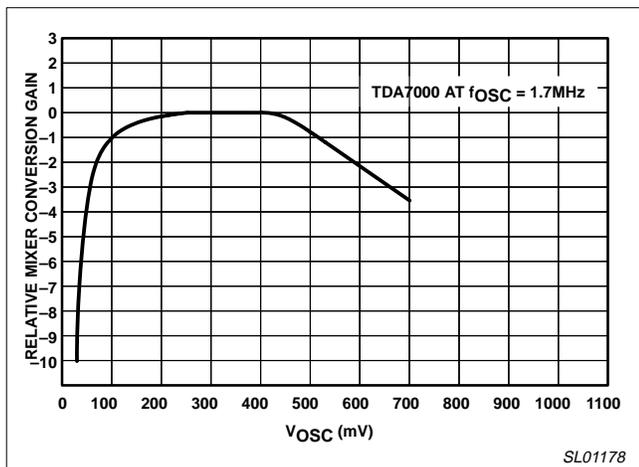
**Figure 5. Relative Mixer Conversion Gain**
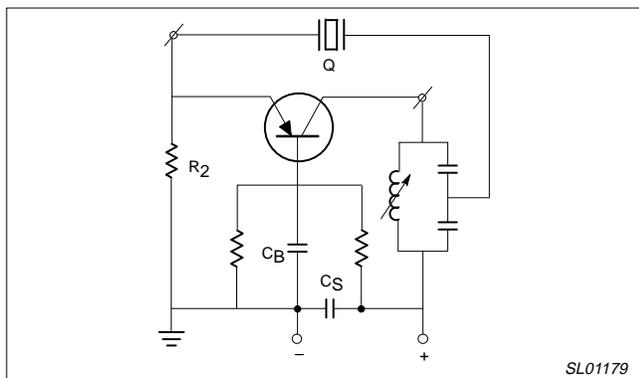
Figure 6.

To obtain a crystal oscillator with the TDA7000 1-pin concept, a parallel circuit configuration as shown in Figure 7 has to be used.

Explanation of this circuit:

1. Without the parallel resistor RP—
   Figure 8 shows the relevant part of the equivalent circuit. There are three frequencies where the circuit is in resonance (see Figure 9, and the frequency response for "impedance" and "phase", shown in Figure 10). The real part of the highest possible oscillation frequency dominates, and, as there is also a zero-crossing of the imaginary part, this highest frequency will be the oscillator frequency. However, this frequency (fPAR) is not crystal-controlled; it is the LC oscillation, in which the parasitic capacitance of the crystal contributes.

2. With parallel resistor RP—
   The frequency response (in "amplitude" and "phase") of the oscillator circuit of Figure 7 with RP is given in Figure 11. As the resistor value of RP is large related to the value of the crystal series resistance R1 or R3, the influence of RP at crystal resonances is negligible. So, at crystal resonance (see Figure 9b), R3 causes a circuit damping

$$ R \ = \ \frac{1}{W^2} \cdot R_3 \cdot C_1{}^2 \ + \ R_3 \left(1 \ + \ \frac{C_2}{C_1} \right)^2 $$

However, at the higher LC-oscillation frequency f_{PAR} (see Figure 9c), R_P reduces the circuit impedance R_O to

$$ \frac{R_O \cdot R_{DAMPING}}{R_O \ + \ R_{DAMPING}} \ = \ R_C $$

where

$$ R_{DAMPING} \ = \ \frac{1}{W^2} \cdot R_P \cdot C_1{}^2 \ + \ R_P \left(1 \ + \ \frac{C_2}{C_1} \right)^2 $$

Thus a damping resistor parallel to the crystal (Figure 7) damps the parasitic LC oscillation at the highest frequency. (Moreover, the imaginary part of the impedance at this frequency shows incorrect zero-crossing.)

Taking care that $R_P > R_{SERIES}$, the resistor is too large to have influence on the crystal resonances. Then with the impedance R_C at the parasitic resonance lower than R at crystal resonance, oscillation will only take place at the required crystal frequency, where impedance is maximum and phase is correct (in this example, at third-overtone resonance).

Remarks:
1. It is advised to avoid inductive or capacitive coupling of the oscillator tank circuit with the RF input circuit by careful positioning of the components for these circuits and by avoiding common supply or ground connections.

The IF Amplifier

Selectivity
Normal selectivity in the TDA7000 is a fourth-order low-pass and a first-order high-pass filter. This selectivity can be split up in a Sallen and Key section (Pins 7, 8, 9), a bandpass filter (Pins 10, 11), and a first-order low-pass filter (Pin 12).

Some possibilities for obtaining required selectivity are given:

1. In the basic application circuit, Figure 12a, the total filter has a bandwidth of 7kHz and gives a selectivity at 25kHz IF frequency of 42dB.
   In this filter the lower limit of the passband is determined by the

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value of C4 at Pin 11, where C3 at Pin 10 determines the upper limit of the bandpass filter section.

2. To obtain a higher selectivity, there is the possibility of adding a coil in series with the capacitor between Pin 11 and ground. The so-obtained fifth-order filter has a selectivity at 25kHz of 57dB (see Figure 12b).

3. If this selectivity is still too small, there is a possibility of increasing the 25kHz selectivity to 65dB by adding a coil in series with the capacitor at Pin 11 to ground. In this application, where at 5kHz IF frequency an adjacent channel at -30kHz will cause a (30-5)=25kHz interfering IF frequency, the pole of the last-mentioned LC filter (trap function) is at 25kHz (see Figure 12c).

For cordless telephone sets with channels at 15kHz distance, the filter characteristics are optimum as shown in the curves in Figure 13, in which case the filters are dimensioned for 5kHz IF bandwidth (instead of 7kHz). So for this narrow channel spacing application, the required selectivity is obtained by reducing the IF bandwidth; this at the cost of up to 2dB loss in sensitivity.

NOTE:
At 5kHz IF frequency adjacent channels at +15kHz give undesired IF frequencies of 20kHz and 10kHz, respectively.

Limiter/Amplifier
The high gain of the limiter/amplifier provides AVC action and effective suppression of AM modulation. DC feedback of the limiter is decoupled at Pin 15.

The Signal Demodulator
The signal demodulator is a quadrature demodulator driven by the IF signal from the limiter and by a phase-shifted IF signal derived from an all-pass filter (see Figure 14).

This filter has a capacitor connected at Pin 17 which fixes the IF frequency. The IF frequency is where a 90 degree phase shift takes care of the center position in the demodulator output characteristics

(see Figure 15, showing the demodulator output (at Pin 4) as a function of the frequency, at 1mV input signal).

The AF Output Stage
The signal demodulator output is available at Pin 4, where a capacitor, C, serves for elimination of IF harmonics. This capacitor also influences the audio frequency response. The output from this stage, available at Pin 2, has an audio frequency response as shown in Figure 16, curve a. The output at Pin 2 can be muted.


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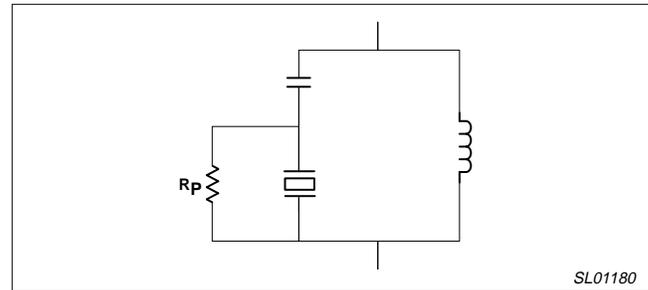
Figure 7.

Output Signal Filtering
Output signal filtering is required to suppress the IF harmonics and interference products of these harmonics with the higher-order bessel components of the modulation. Active filtering with operational amplifiers has been used (see Figure 17). The frequency response of such a filter is given in Figure 16, Curve b, for an active second-order filter with an additional passive RC filter.

Output Amplification
The dimensioning of the operational amplifier of Figure 17a results in no amplification of the AF signal. In case amplification of this op amp is required, a feedback resistor and an RC filter at the reverse input can be added (see Figure 17b, for about 30dB amplification).


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Figure 8.

a. At f_1   **b. At f_3**   **c. At f_{PAR}**   SL01182
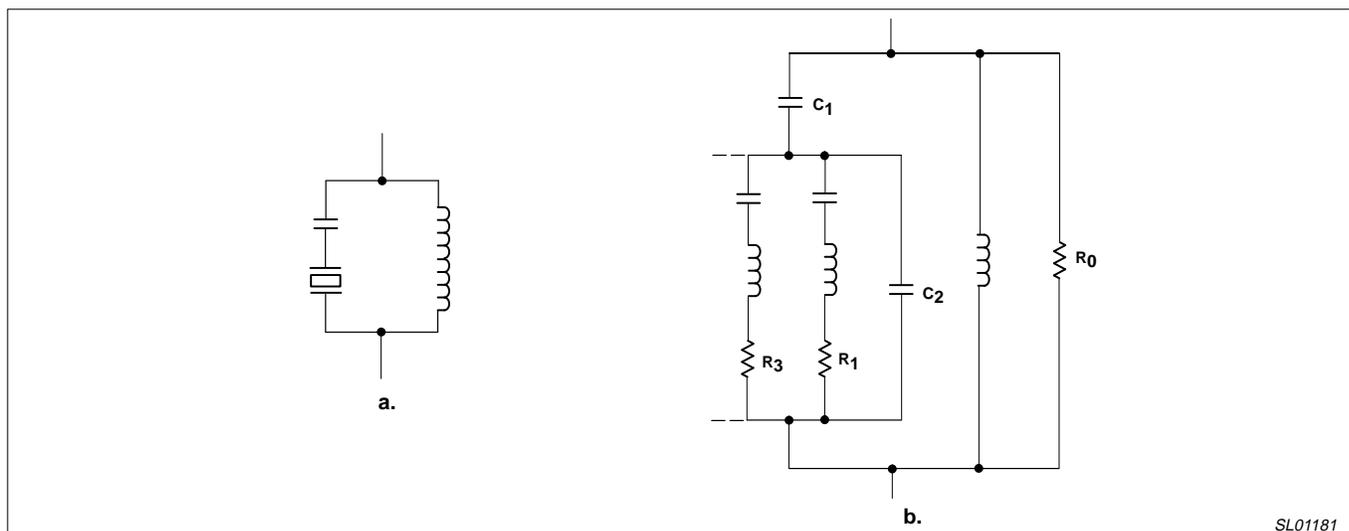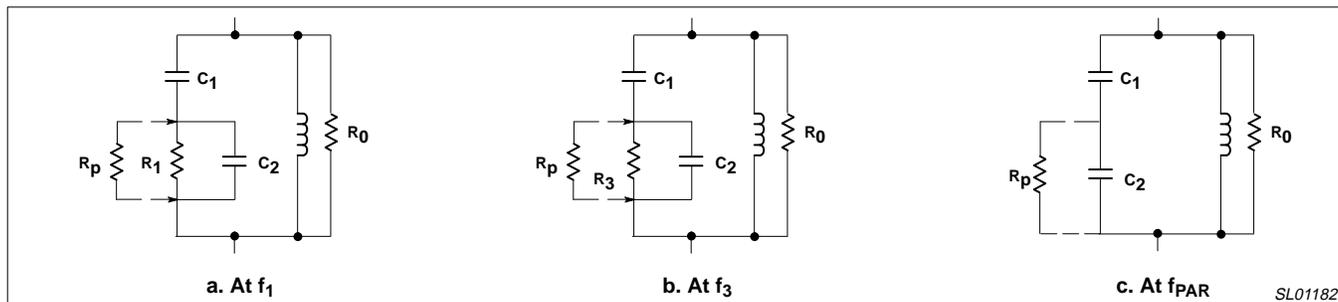
Figure 9.

MEASUREMENTS

For sensitivity, signal handling, and noise behavior information in a standard application as shown in Figure 18, the signal and noise output as a function of input signal has been measured at 1.7MHz, at 400Hz modulation where the deviation is ±2.5kHz (see Figure 19). As a result the S+N/N ratio is as given in Figure 19, Curve 3.

APPENDIX

RF-Tuned Input Circuit at 46MHz

In Figure 20 a filter is given which matches at 46MHz a 75Ω aerial to the input of the TDA7000. Extra suppression of RF frequencies outside the passband has been obtained by a trap function.

RF Pre-Stage at 46MHz

For better quality receivers at 46MHz, an RF pre-stage can be added (see Figure 21) to improve the noise figure. Without this transistor, a noise figure F=11dB was found. With a transistor (BFY 90) with RC coupling at 3mA, F=7dB or at 6mA F=6dB.

With a transistor stage having an LC-tuned circuit, one can obtain F=7dB at I=0.3mA.

NOTE:

The noise figure includes image-noise.

An LC Oscillator at 1.7MHz

An LC oscillator can be designed with or without AFC. If for better stability external AFC is required, one can make use of the DC output of the signal demodulator, which delivers 80mV/kHz at a DC level of 0.65V to +supply. An LC oscillator as shown in Figure 22a, using a capacitor with a temperature coefficient of -150ppm, gives an oscillator signal of 190mV, with a temperature stability of 1kHz/50°.

With the use of AFC, as shown in Figure 22b, one can further improve the stability, as AFC reduces the influence of frequency changes in the transmitter (due to temperature influence or aging). The given circuit gives a factor 2 reduction. Note that the temperature behavior of the AFC diode has to be compensated. In Figure 22b, with BB405B having a capacitance of 18pF at the reverse voltage V4=0.7V, the temperature coefficient of the capacitor C has to be -200ppm.

AF Output Possibilities

The AF output from the signal demodulator, available at Pin 4, depends on the slope of the demodulator as shown in Figure 15. The TDA7000 AF output is also available at Pin 2 (see Figure 23). The important difference between the output at Pin 2 and the output at Pin 4 is that the Pin 4 output is amplified and limited before it is led to Pin 2 (see Figure 24). Moreover, the Pin 2 output is controlled by the mute function, a mute which operates in case the received signal is bad as far as noise and distortion are concerned.

The Pin 2 output delivers a higher AF signal; however, the AF output spectrum shows more mixing products between IF harmonics and modulation frequency harmonics. This is due to the "limited output situation" at Pin 2. In narrow-band application with relatively large deviation these products are so high that extra AF output filtering is required and, moreover, the IF center frequency has to be higher compared to the concept, using AF output at Pin 4.

So for those sets where the mute/squelch function of the TDA7000 is not used, and the higher AF output is not required, the use of the AF output at Pin 4 is advised, giving less interfering products and simplified AF output filtering.

Squelch and Squelch Indication

The TDA7000 contains a mute function, controlled by a "waveform correlator", based on the exactness of the IF frequency.

The correlation circuit uses the IF frequency and an inverted version of it, which is delayed (phase-shifted) by half the period of nominal IF. The phase shift depends on the value of the capacitor at Pin 18 (see Figure 23).

This mute also operates at low field strength levels, where the noise in the IF signal indicates bad signal definition. (The correlation between IF signal and the inverted phase-shifted version is small due to fluctuations caused by noise; see Figure 25.) This field strength-dependent mute behavior is shown in Figure 26, Curve 2, measured at full mute operation. The AF output is not "fast-switched" by the mute function, but there is a "progressive (soft muting) switch". This soft muting reduces the audio output signal at low field strength levels, without degradation of the audio output signal under these conditions.

The capacitor, C_1, at Pin 1 (see Figure 23) determines the time constant for the mute action.

Part operation of the mute is also a possibility (as shown by Figure 26, Curve 3) by circuiting a resistor in parallel with the mute capacitor at Pin 1.

In Figure 26 the small signal behavior with the mute disabled has been given also (see Curve 1).

One can make use of the mute output signal, available at Pin 1, to indicate squelch situation by an LED (see Figure 27). Operation of the mute by means of an external DC voltage (see Figure 28) is also possible.

Bell Signal Operation

To avoid tone decoder filters and tone decoder rectifiers for bell signal transmission, use can be made of the mute information in the TDA7000 to obtain a bell signal without the transmission of a bell pilot signal.

With a handset receiver as shown in Figure 23 in the "standby" position, the high mute output level turns amplifier 1 off via transistor T1 until a correct IF frequency is obtained. This situation appears at the moment that a bell signal switches the base unit in transmission mode. If the transmitted field strength is high enough to be received above a certain noise level, the mute level output goes down; T1 will be closed and amplifier 1 starts operating. However, due to feedback, this amplifier starts oscillating at a low frequency (a frequency dependent on the filter concept). This low-frequency signal serves for bell signal information at the loudspeaker.

Switching the handset to "talk" position will stop oscillation. Then amplifier 1 serves to amplify normal speech information.

Mute at Dialing

During dial operation, the key-pulser IC delivers a mute voltage. This voltage can be used to mute the AF amplifier, e.g., via T1 of the bell signal circuit/amplifier (see Figure 23).

CONCLUSIONS

The application of the TDA7000 in the remote unit (handset) as narrow-band FM receiver is very attractive, as the TDA7000 reduces assembly and post-production alignment costs. The only tunable circuit is the oscillator circuit, which can be a simple crystal-controlled tank circuit.

A TDA7000 with:
- fifth-order IF filter
- third-order AF output filter
- matched input circuit
- crystal oscillator tank circuit
- disabled mute circuit

gives a sensitivity of 2.5μV for 20dB signal-to-noise ratio, at adjacent channel selectivity of 40dB (at 15kHz) in cordless telephone application at 1.7MHz.

The TDA7000 circuit is:
- without an RF pre-stage
- without RF-tuned circuits
- without oscillator transistor (and its components)
- without LC or ceramic filters in IF and demodulator.

For improved performance, the TDA7000 circuit can be expanded:

- with an RF pre-stage and RF selectivity
- with higher-order IF filtering
- with mute/squelch function.

For reduced performance the TDA7000 circuit can be simplified:
- to LC-tuned oscillator
- to lower-order IF filter
- to bell signal operation without pilot transmission.

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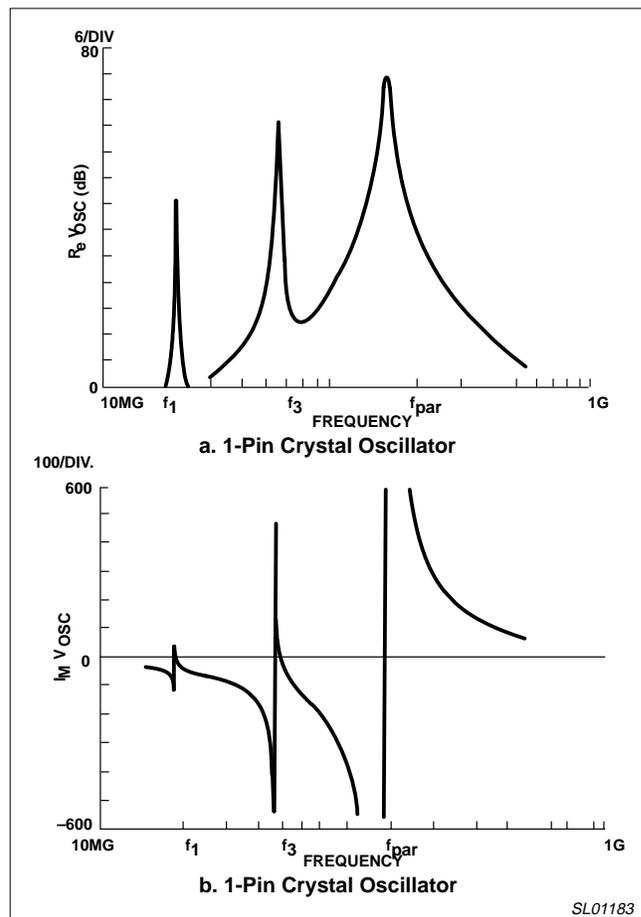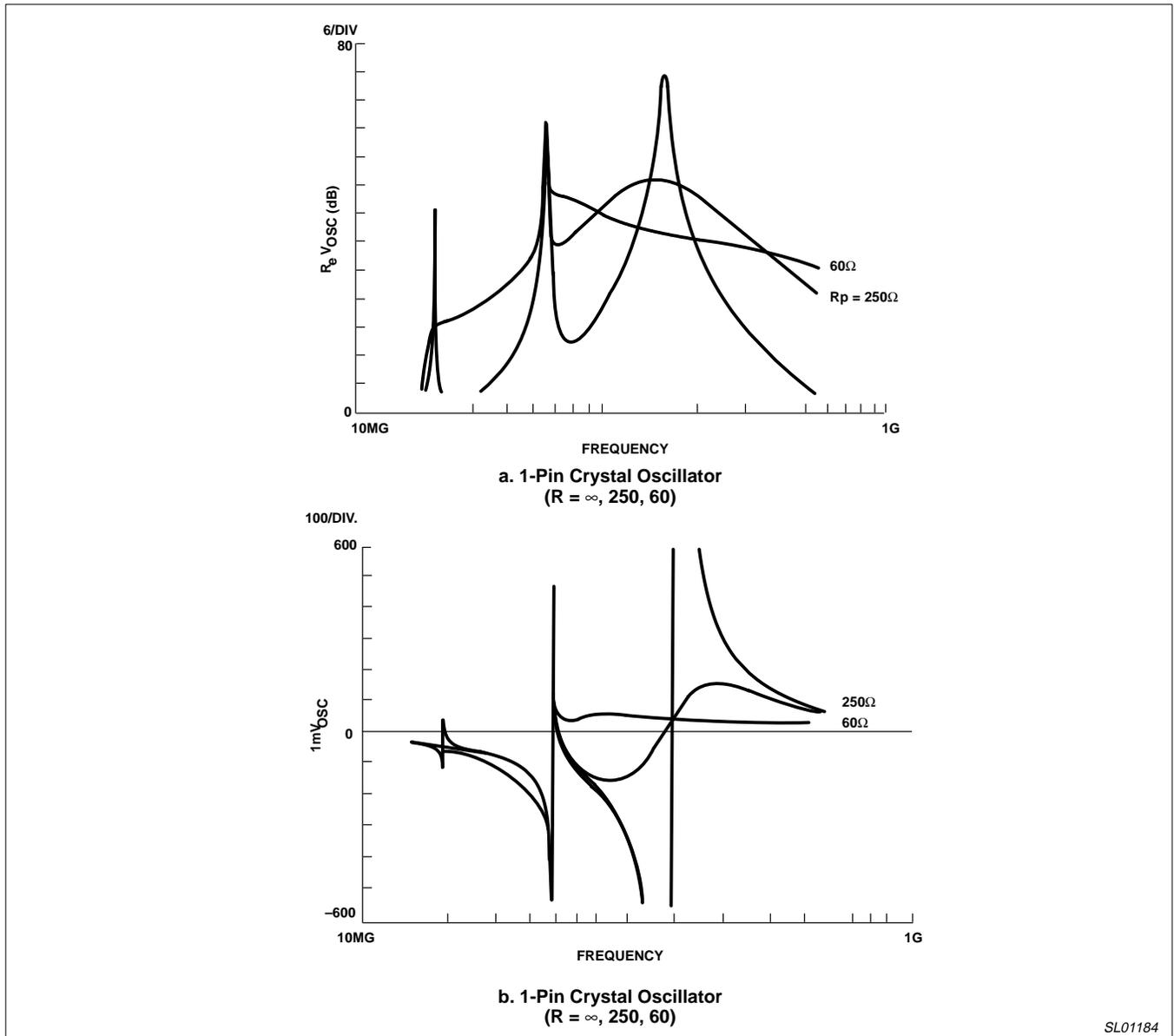
a. 1-Pin Crystal Oscillator

b. 1-Pin Crystal Oscillator

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Figure 10.

a. 1-Pin Crystal Oscillator
(R = ∞, 250, 60)

b. 1-Pin Crystal Oscillator
(R = ∞, 250, 60)
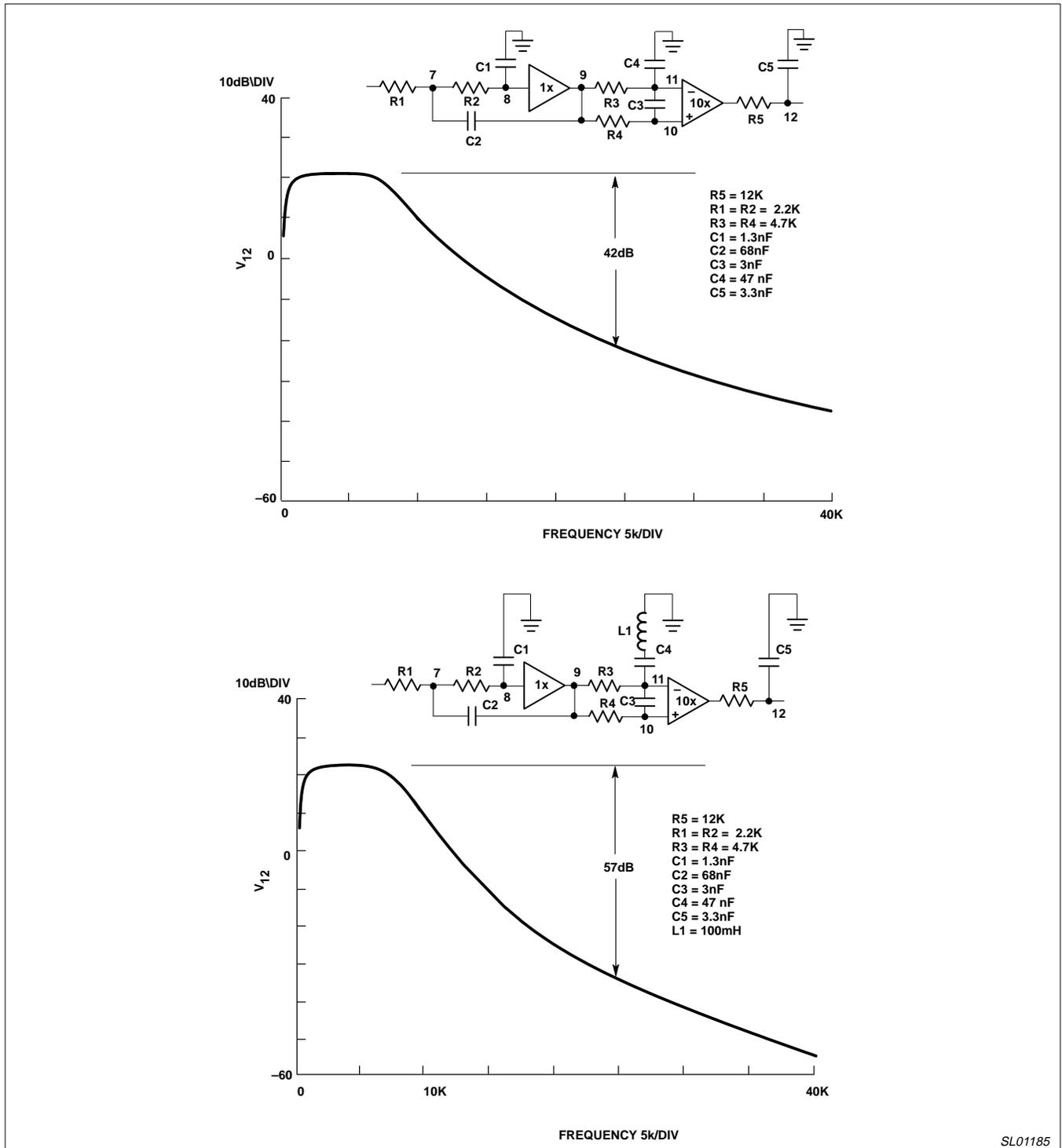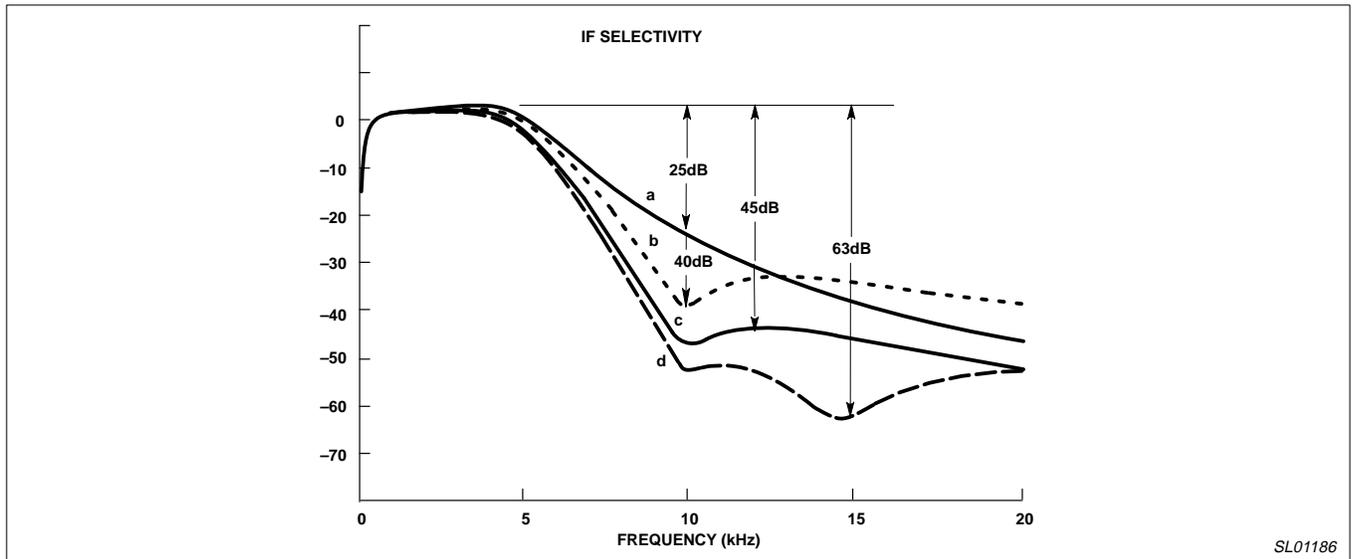
Figure 11.

Figure 12.

Figure 12 (Continued)
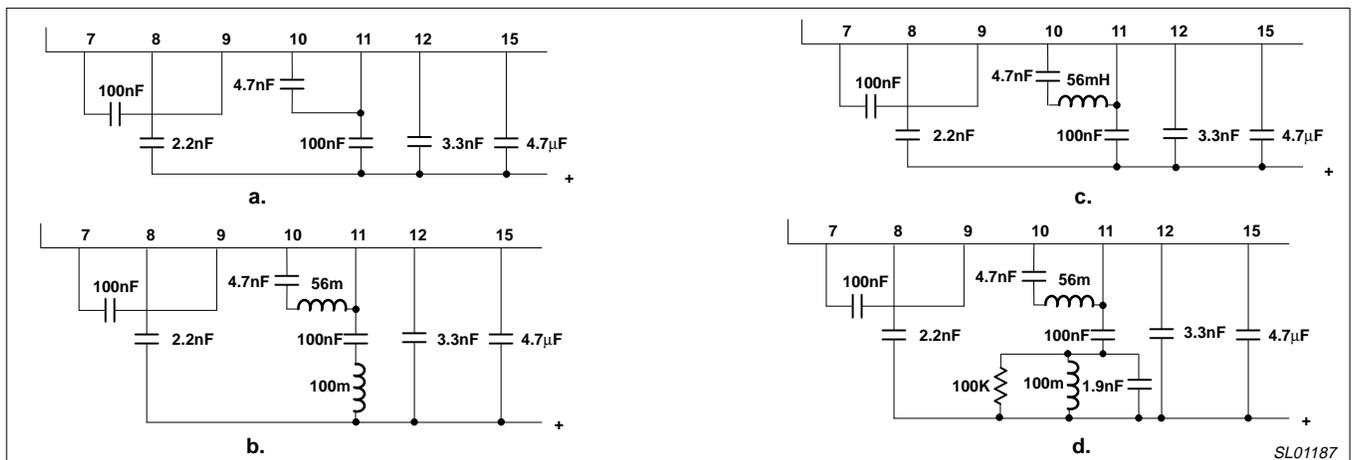
Figure 13.
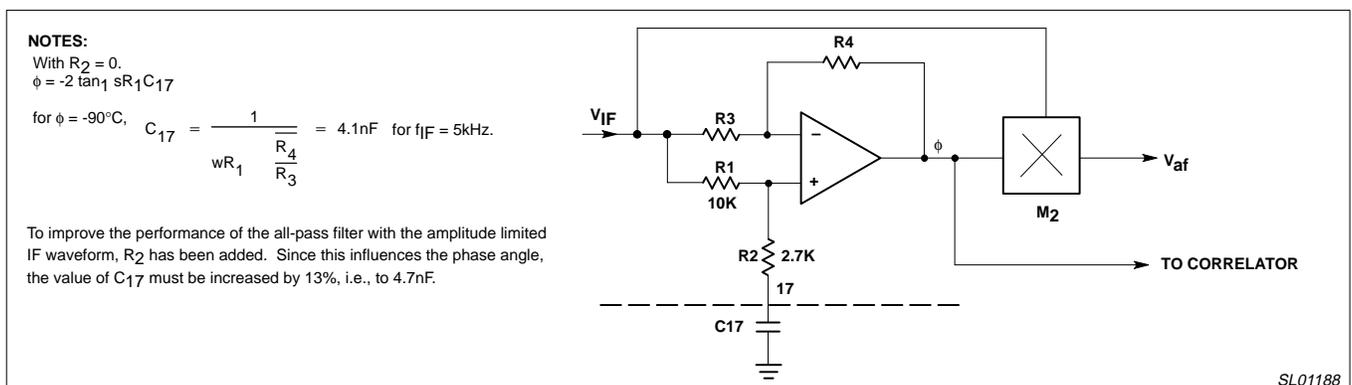
Figure 14. FM Demodulator Phase-Shift Circuit (All-Pass Filter)
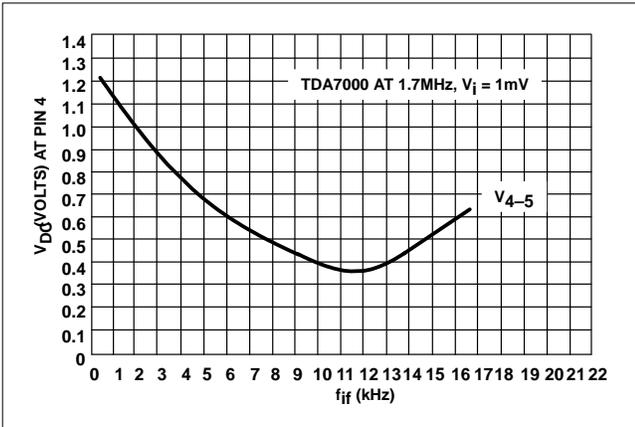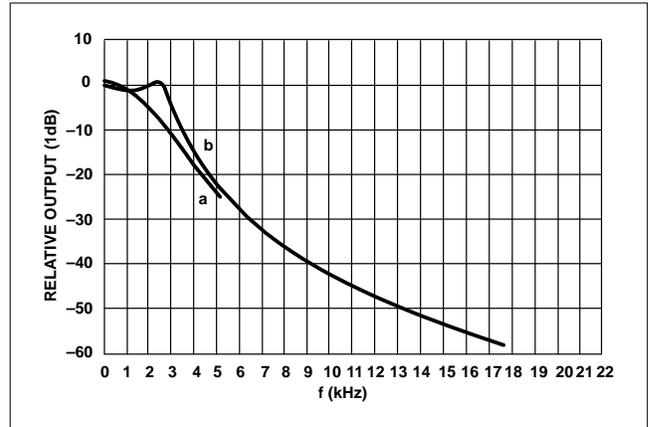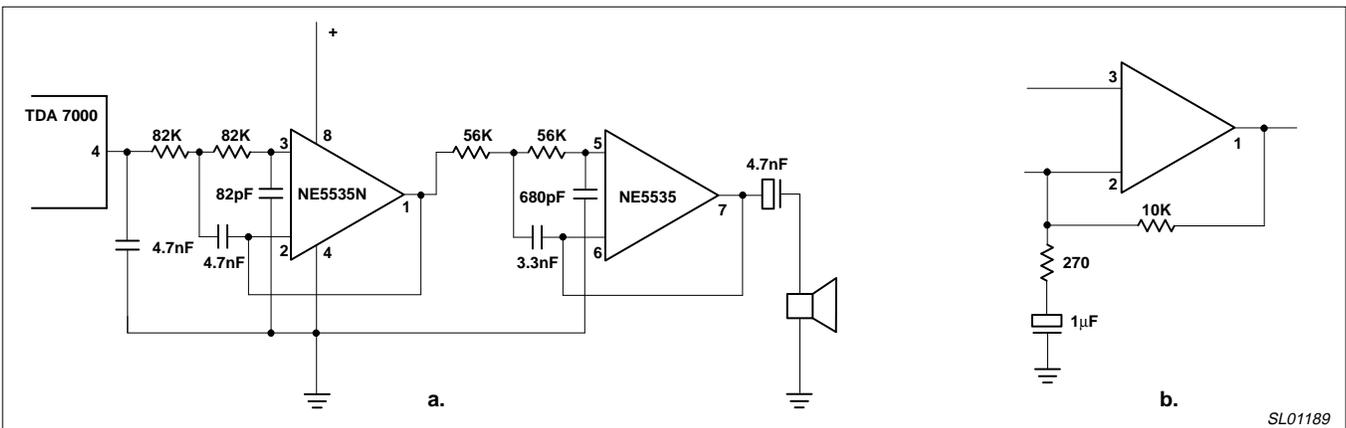
Figure 15.

Figure 16.

Figure 17.
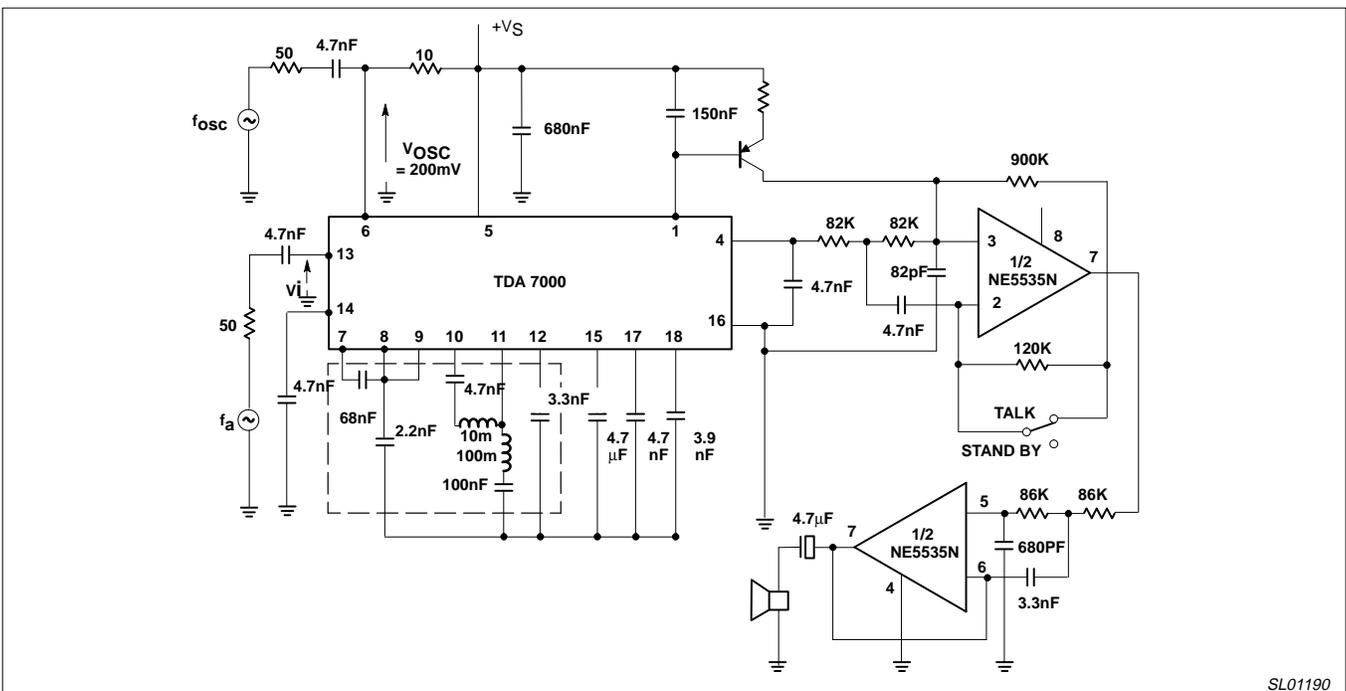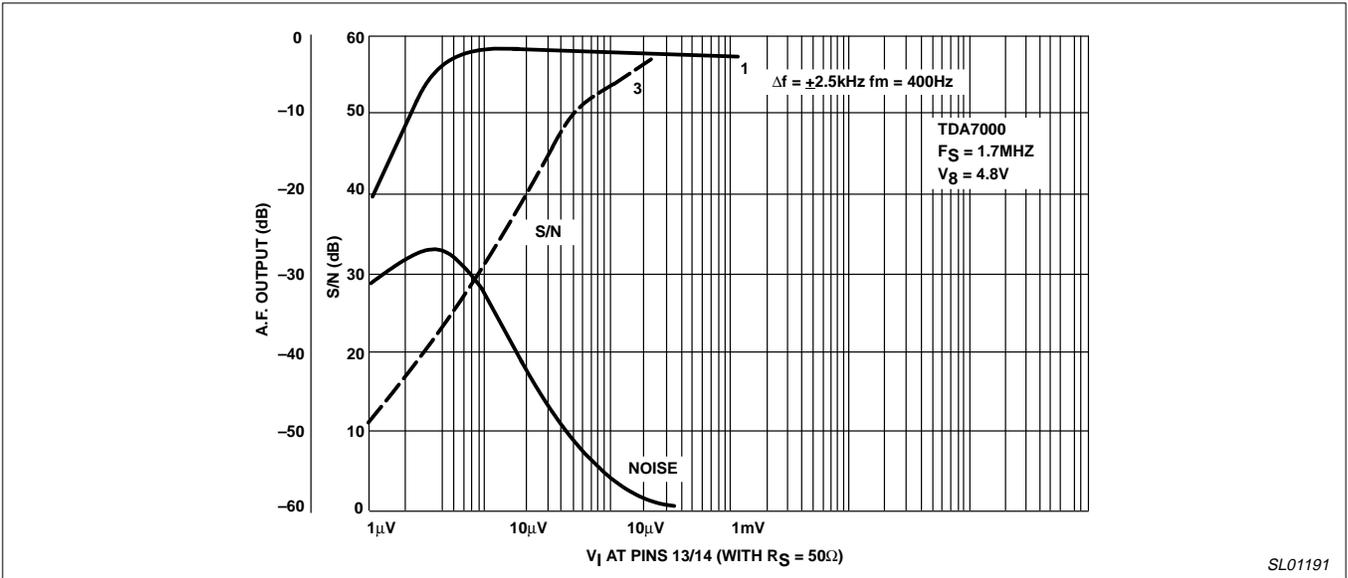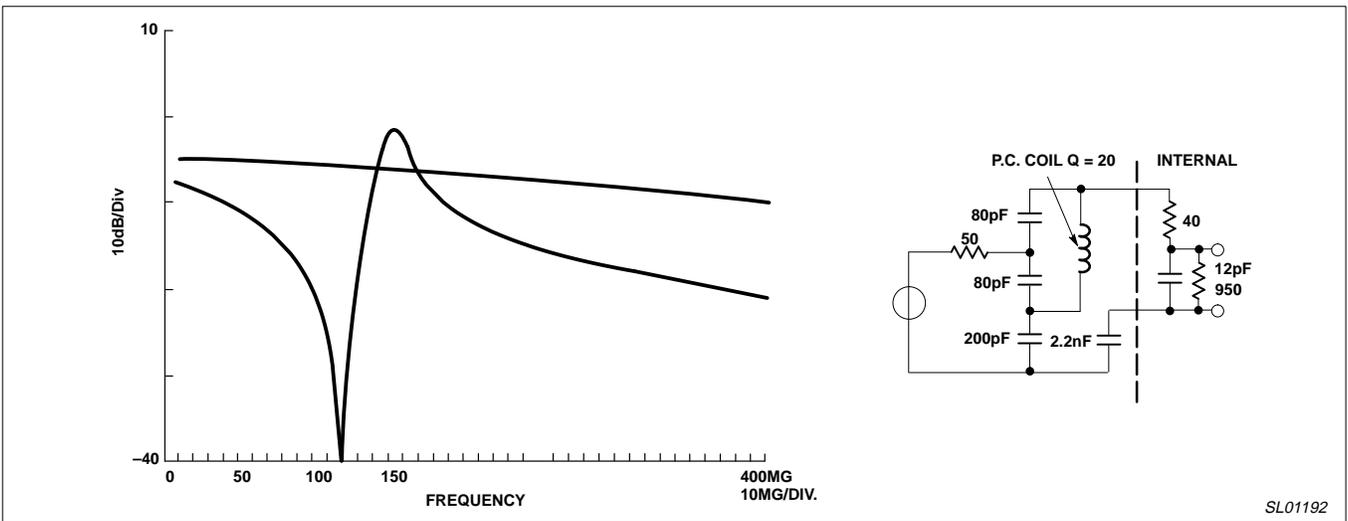
**Figure 18.**
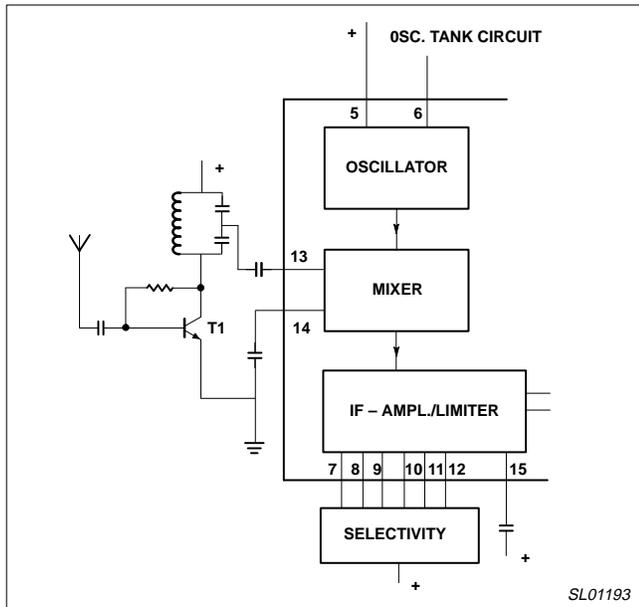
Figure 19.
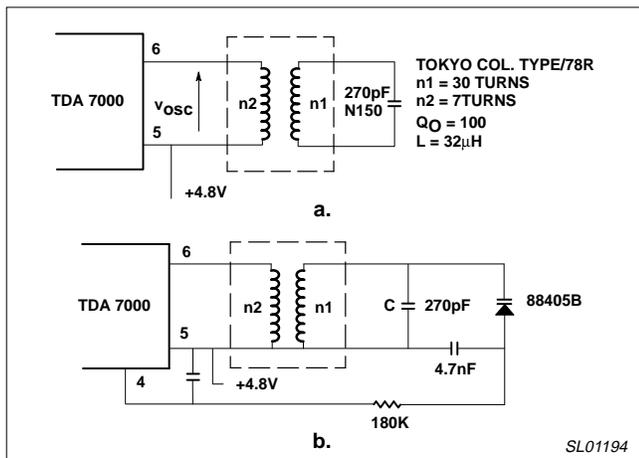
Figure 20.
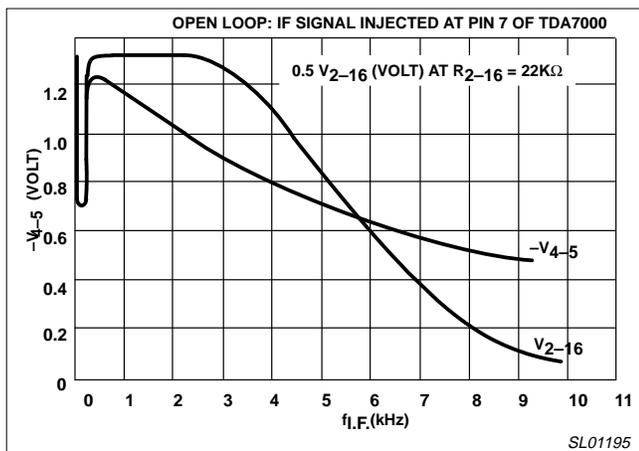
Figure 21.

Figure 22.

Figure 23. Demodulator Characteristics
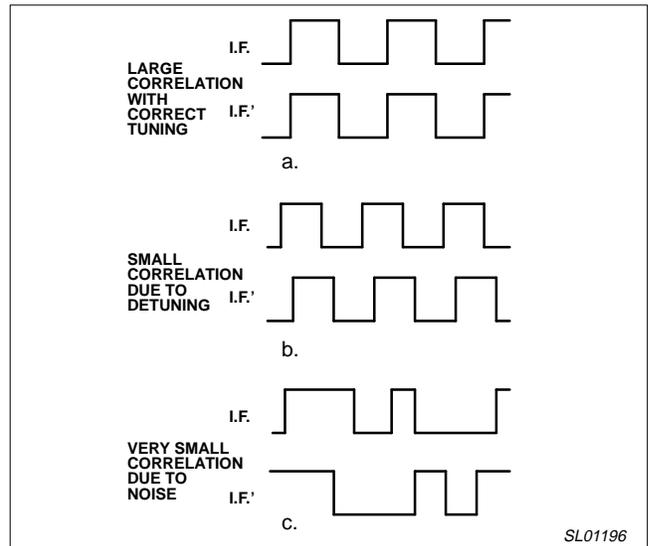
**Figure 24. Function of the Correlation Muting System**
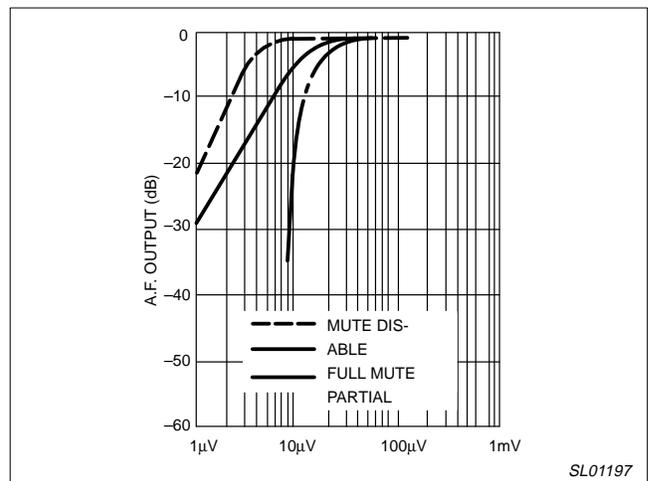

Figure 25.
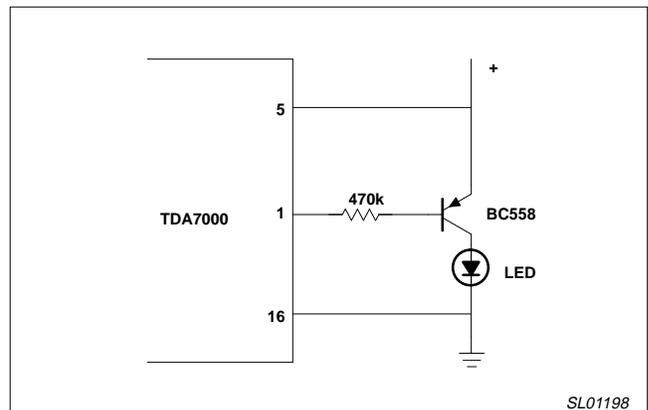
Figure 26. Function of the Correlation Muting System
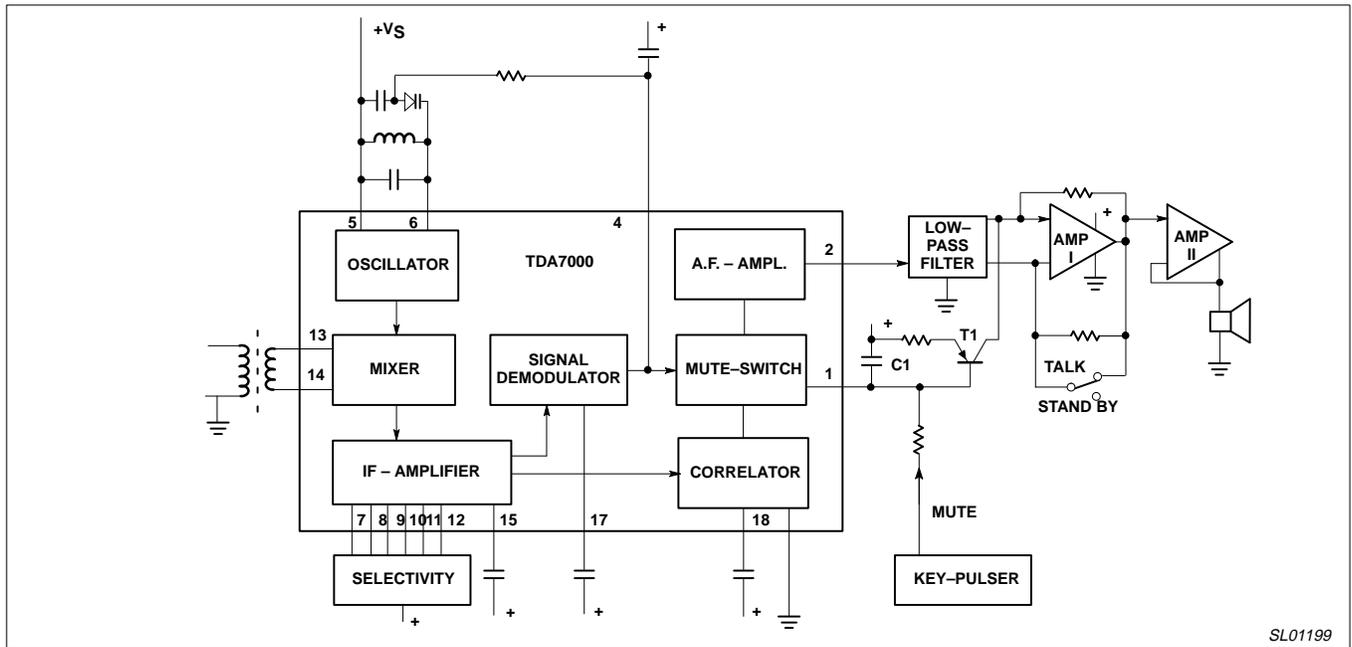
Figure 27. Remote Unit Receiver: 1.7MHz

Figure 28.