

## LM1865/LM1965/LM2065 Advanced FM IF System

### General Description

Reduced external component cost, improved performance, and additional functions are key features to the LM1865/LM1965/LM2065 FM IF system. The LM1865 and LM2065 are designed for use in electronically tuned radio applications. These versions contain both deviation and signal level stop circuitry in addition to an open-collector stop output. The LM1865 and LM2065 differ only in the direction of the AGC output voltage they generate on pin 18. The LM1865 generates a reverse AGC voltage (ie: decreasing AGC voltage with increasing signal) and the LM2065 generates a forward AGC voltage (ie: increasing AGC voltage with increasing signal.) The LM1965 has a reverse AGC characteristic. The LM1965 is designed for use in manually tuned radios and provides a deviation and signal level mute function in addition to a pin that disables the mute function when grounded. All three versions are offered in both 20 pin D.I.P. and S.O. packages.

### Features

- On-chip buffer to provide gain and terminate two ceramic filters

- Low distortion 0.1% typical with a single tuned quadrature coil for 100% modulation.
- Broad off frequency distortion characteristic
- Low THD at minimum AFT offset
- Meter output proportional to signal level
- Mute function with mute disable and soft deviation mute for LM1965
- Stop detector with open-collector output for LM1865/LM2065
- Adjustable signal level mute/stop threshold, controlled either by ultrasonic noise in the recovered audio or by the meter output
- Adjustable deviation mute/stop threshold
- Separate time constants for signal level and deviation mute/stop
- Dual threshold AGC eliminates need for local/distance switch and offers improved immunity from third order intermodulation products due to tuner overload
- User control of both AGC thresholds
- Excellent signal to noise ratio, AM rejection and system limiting sensitivity

### Block Diagram

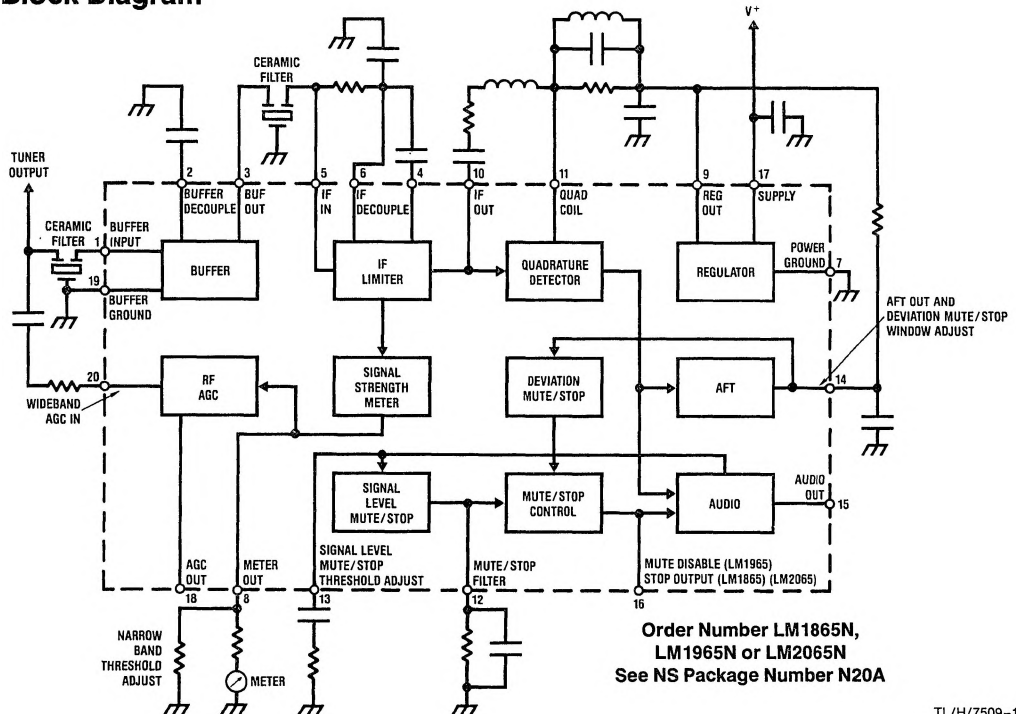


FIGURE 1

TL/H/7509-1

## Absolute Maximum Ratings

If Military/Aerospace specified devices are required, contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage, Pin 17	16V
Package Dissipation (Note 1)	2.0W
Storage Temperature Range	-55°C to +150°C
Operating Temperature Range	-20°C to +85°C
Max Voltage on Pin 16 (Stop Output) for LM1865, LM2065	16V

### Soldering Information

Dual-In-Line Package	
Soldering (10 seconds)	260°C
Small Outline Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

## Electrical Characteristics

Test Circuit,  $T_A = 25^\circ\text{C}$ ,  $V^+ = 12\text{V}$ ; S1 in position 2; S2 in position 1; and S3 in position 2 unless indicated otherwise

Parameter	Conditions	Min	Typ	Max	Units
<b>STATIC CHARACTERISTICS</b>					
Supply Current			33	45	mA
Pin 9, Regulator Voltage			5.7		V
Operating Voltage Range	(See Note 2)	7.3		16	V
Pin 18, Output Leakage Current	Pin 20 Open, $V_{IF} = 0$ , S3 in Position 1		0.1		$\mu\text{A}$
Pin 16, Stop Low Output Voltage (LM1865 Only)	S1 in Position 1, S2 in Position 3		0.3		V
Pin 16, Stop High Output Leakage Current (LM1865 Only)	S2 in Position 2, $V_{14} = V_9$		0.1		$\mu\text{A}$
Pin 15, Audio Output Resistance			4.7		k $\Omega$
Pin 1, Buffer Input Resistance	Measured at DC		350		$\Omega$
Pin 3, Buffer Output Resistance	Measured at DC		350		$\Omega$
Pin 20, Wide Band Input Resistance	Measured at DC		2		$\Omega$
Pin 8, Meter Output Resistance			1		k $\Omega$
<b>DYNAMIC CHARACTERISTICS</b> $f_{\text{MOD}} = 400\text{ Hz}$ , $f_o = 10.7\text{ MHz}$ , Deviation = $\pm 75\text{ kHz}$					
-3 dB Limiting Sensitivity	IF Only (See Note 3)		60	120	$\mu\text{Vrms}$
Buffer Voltage Gain	$V_{IN}$ Pin 1 = 10 mVrms at 10.7 MHz	19	22	25	dB
Recovered Audio	$V_{IF} = 10\text{ mVrms}$ , $V_{14} = V_9$	275	320	470	mVrms
Signal-to-Noise	$V_{IF} = 10\text{ mVrms}$ , $V_{14} = V_9$ (See Note 4)	70	84		dB
AM Rejection	$V_{14} = V_9$				
	$V_{IF} = 1\text{ mV}$ , 30% AM Mod $V_{IF} = 10\text{ mV}$ , 30% AM Mod	50 50	60 60		dB dB
Minimum Total Harmonic Distortion	$V_{IF} = 10\text{ mV}$		0.1	0.35	%
THD at Frequency where $V_{14} = V_9$ (Zero AFT Offset)	$V_{IF} = 10\text{ mV}$ , Tune until $V_{14} = V_9$		0.1	0.45	%
THD $\pm 10\text{ kHz}$ from Frequency where $V_{14} = V_9$	$V_{IF} = 10\text{ mV}$		0.15		%
AFT Offset Frequency for Deviation Mute (LM1965 Only)	$V_{IF} = 10\text{ mV}$ , Audio = -3 dB, S2 in Position 4 Offset = (Frequency for -3 dB Audio) - (Frequency where $V_{14} = V_9$ )		$\pm 62$		kHz
AFT Offset Frequency for Low Stop Output at Pin 16 (LM1865 and LM2065 Only)	$V_{IF} = 10\text{ mV}$ , S2 in Position 3, $f_{\text{MOD}} = 0$ Offset = (Frequency for Pin 16 Low) - (Frequency where $V_{14} = V_9$ )		$\pm 50$		kHz
Ultrasonic Mute/Stop Level Threshold	$V_{14} = V_9$ , S1 in Position 3 (See Note 5) $V_{IF} = 10\text{ mV}$ $f_{\text{MOD}} = 100\text{ kHz}$ S2 in Position 4 (LM1965) S2 in Position 3 (LM1865/LM2065) Amount of Deviation where Audio Mutes (LM1965) Amount of Deviation where $V_{16} \rightarrow \text{Low}$ (LM1865, LM2065)		60		kHz

## Electrical Characteristics

Test Circuit,  $T_A = 25^\circ\text{C}$ ,  $V^+ = 12\text{V}$ ; S1 in position 2; S2 in position 1; and S3 in position 2 unless indicated otherwise  
(Continued)

Parameter	Conditions	Min	Typ	Max	Units
<b>DYNAMIC CHARACTERISTICS</b> $f_{\text{MOD}} = 400\text{ Hz}$ , $f_0 = 10.7\text{ MHz}$ , Deviation = $\pm 75\text{ kHz}$ (Continued)					
Pin 13 Mute/Stop Threshold Voltage	V14 = V9, S1 in Position 4 S2 in Position 4 (LM1965) S2 in Position 3 (LM1865, LM2065) V13 where Audio Mutes (LM1965) V13 where V16 $\rightarrow$ Low (LM1865, LM2065)		220		mV
Amount of Muting (LM1965 Only)	S2 in Position 4, S1 in Position 1, $V_{\text{IF}} = 10\text{ mV}$		66		dB
Amount of Muting with Pin 13 and Pin 16 Grounded	S1 in Position 1 V14, = V9, $V_{\text{IF}} = 10\text{ mV}$		0		dB
Narrow Band AGC Threshold	Increase IF Input until $I_{\text{AGC}} = 0.1\text{ mA}$ Pin 20 = 30 mVrms (See Note 6)	100	210	300	$\mu\text{Vrms}$
Wide Band AGC Threshold	$V_{\text{IF}} = 100\text{ mVrms}$ Increase Signal to Pin 20 until $I_{\text{AGC}} = 0.1\text{ mA}$ (See Note 6)	5	12	22	mVrms
Pin 18, Low Output Voltage (LM1865 and LM1965 only)	$V_{\text{IN}}$ Pin 20 = 100 mV, $V_{\text{IF}} = 100\text{ mVrms}$		0.2	0.5	V
Pin 18, High Output Voltage (LM2065 only)	$V_{\text{IN}}$ Pin 20 = 100 mV, $V_{\text{IF}} = 100\text{ mVrms}$ , (See Note 6)		11.7		V
Pin 8, Meter Output Voltage	$V_{\text{IF}} = 10\ \mu\text{V}$ $V_{\text{IF}} = 300\ \mu\text{V}$ $V_{\text{IF}} = 3\text{ mV}$		0.1 1.1 2.6		V V V

**Note 1:** Above  $T_A = 25^\circ\text{C}$  derate based on  $T_{\text{J(max)}} = 150^\circ\text{C}$  and  $\theta_{\text{JA}} = 60^\circ\text{C/W}$ .

**Note 2:** All data sheet specifications are for  $V^+ = 12\text{V}$  may change slightly with supply.

**Note 3:** When the IF is preceded by 22 dB gain in the buffer, excellent system sensitivity is achieved.

**Note 4:** Measured with a notch at 60 Hz and 20 Hz to 100 kHz bandwidth.

**Note 5:** FM modulate RF source with a 100 kHz audio signal and find what modulation level, expressed as kHz deviation, results in audio mute for the LM1965 or V16  $\rightarrow$  12V for the LM1865/LM2065.

**Note 6:** S3 in Position 3 for LM2065.

## Test Circuit

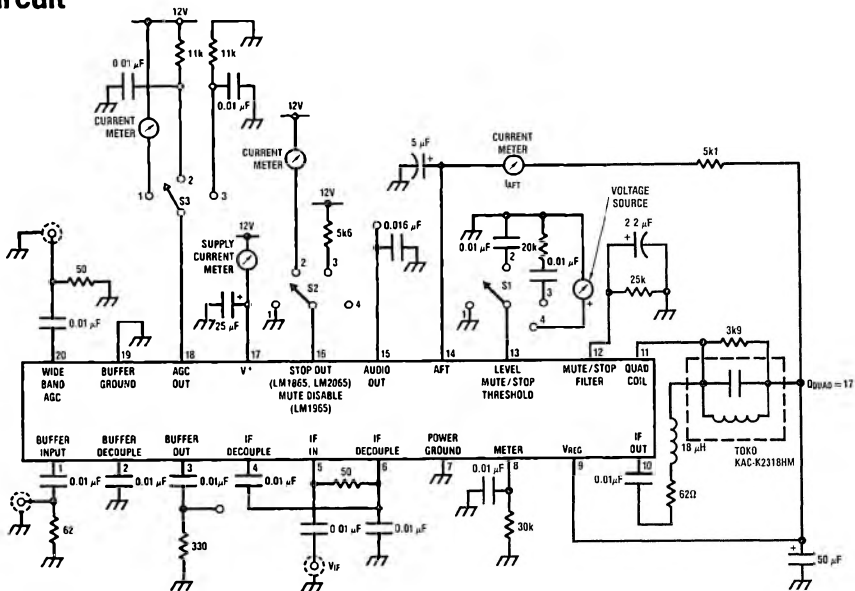
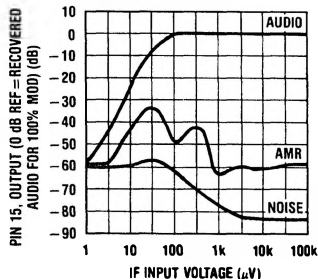


FIGURE 2

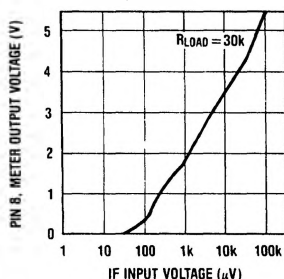
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# Typical Performance Characteristics (from Test Circuit)

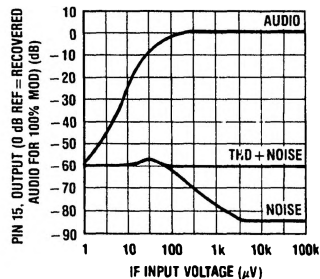
**FM Limiting Characteristics and AM Rejection**



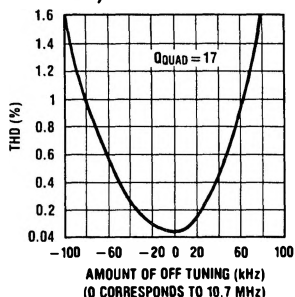
**Pin 8, Meter Output Voltage vs IF Input Level**



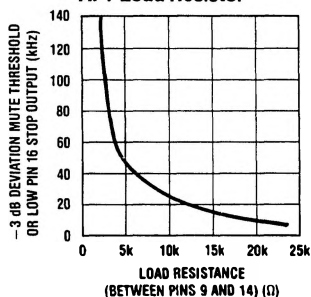
**FM Limiting Characteristics + THD**



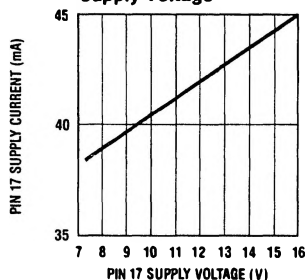
**% THD vs OFF Tuning (Single Tuned Quadrature Coil)**



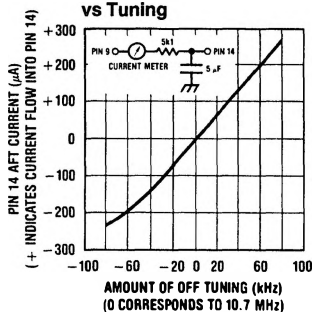
**Deviation Mute/Stop Threshold as a Function of AFT Load Resistor**



**Supply Current vs Supply Voltage**



**Pin 14, AFT Current vs Tuning**



Coils and ceramic filters are available from:

Toko America  
1250 Feehanville Drive  
Mount Prospect, IL 60056  
(312) 297-0070

Murata  
2200 Lake Park Drive  
Smyrna, GA 30080  
(404) 436-1300

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# Application Circuit

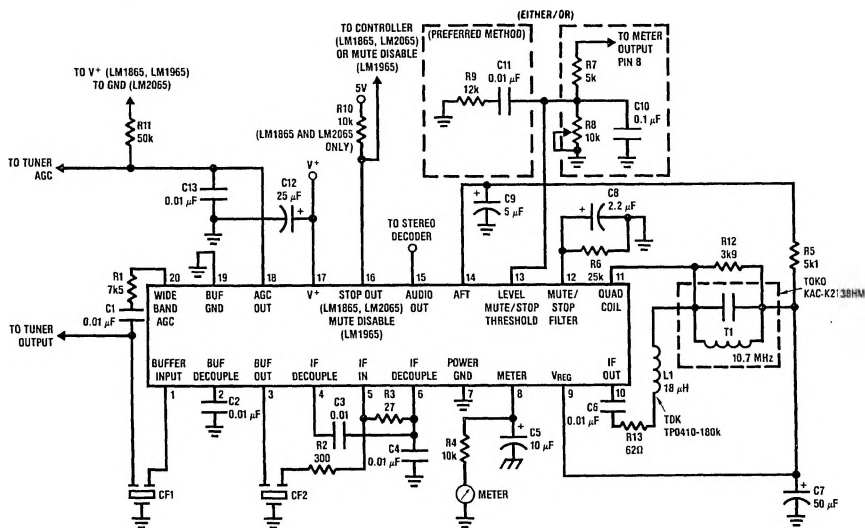


FIGURE 3

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## IC External Components (See Application Circuit)

Component	Typical Value	Comments
C1	0.01 $\mu$ F	AC coupling for wide band AGC input
C2	0.01 $\mu$ F	Buffer and AGC supply decoupling
C3, C4	0.01 $\mu$ F	IF decoupling capacitors
C5	10 $\mu$ F	Meter decoupling capacitor
C6	0.01 $\mu$ F	AC coupling for IF output
C7	50 $\mu$ F	Regulator decoupling capacitor, affects S/N floor
C8	2.2 $\mu$ F	Level mute/stop time constant
C9	5 $\mu$ F	AFT decoupling, affects stop time
C10	0.1 $\mu$ F	Disables noise mute/stop
C11	0.01 $\mu$ F	AC coupling for noise mute/stop threshold adjust
C12	25 $\mu$ F	Supply decoupling
C13	0.01 $\mu$ F	AGC output decoupling capacitor
R1	Tuner Dependent	Wide band AGC threshold adjust
R2, R3	Tuner Dependent	Gain set and bias for IF; R2 + R3 = 330 $\Omega$ to terminate ceramic filter
R4	Meter Dependent	Sets full-scale on meter
R5	5k1	Deviation mute/stop window adjustment
R6	25k	Mute/stop filter, affects stop time
R7	5k	Level mute/stop threshold adjustment
R8	10k Pot	Level mute/stop threshold adjustment
R9	12k	Noise mute/stop threshold adjustment, decrease resistor for lower S/N at threshold, for optimum performance over temp. and gain variation, set this resistor value so that the signal level mute/stop threshold occurs in the radio at 45dB S/N ( $\pm 3$ dB) in mono.
R10	10k	Load for open-collector stop output
R11	50k	AGC output load resistor for open-collector output
R12	3k9	Sets Q of quadrature coil affecting THD, S/N and recovered audio
R13	62 $\Omega$	Optimises minimum THD
L1	18 $\mu$ H $Q_U > 50$ @ 10.7 MHz TDK Electronics TPO410-180K or equivalent	Sets signal swing across quadrature coil, High Q is important to minimize effect variation of Q has on both minimum THD and AFT offset.
T1	$Q_U > 70$ @ 10.7 MHz, L to resonate w/82 pF @ 10.7 MHz TOKO KAC-K2318HM or equivalent	10.7 MHz quadrature coil: $Q_{UL} > 70$
CF1, CF2	Murata SFE10.7ML or equivalent	10.7 MHz ceramic resonators provide selectivity; good group delay characteristics important for low THD of system

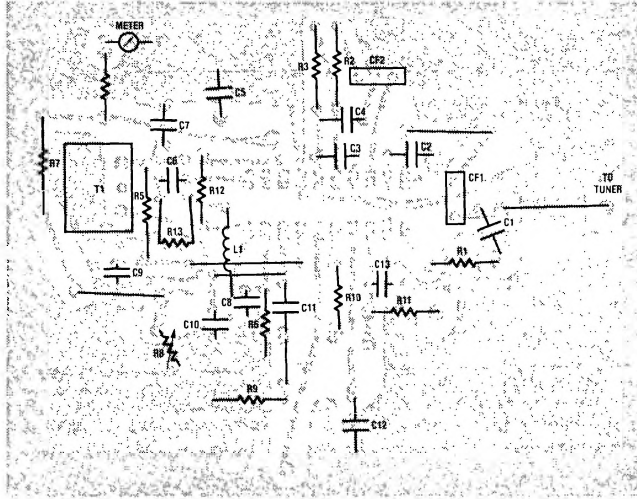
# Typical Application

## LAYOUT CONSIDERATIONS

Although the pinout of the LM1865/LM1965/LM2065 has been chosen to minimize layout problems, some care is required to insure stability. The ground terminal on CF1

should return to both the input signal ground and the buffer ground, pin 19. The ground terminal on CF2 should return to the ground side of C4. The quadrature coil T1 and inductor L1 should be separated from the input circuitry as far as possible.

PC Layout (Component Side)



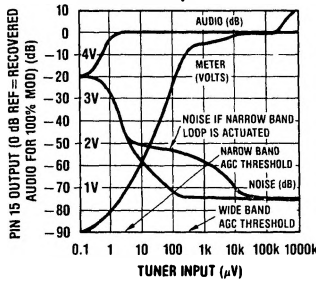
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## PERFORMANCE CHARACTERISTICS OF TYPICAL APPLICATION WITH TUNER

The following data was taken using the typical application circuit in conjunction with an FM tuner with 43 dB of gain, a

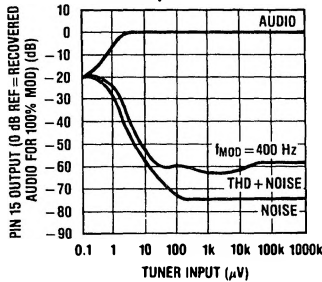
5.5 dB noise figure, and 30 dB of AGC range. The tuner was driven from a 50Ω source. 75 μs of de-emphasis was used on the audio output, pin 15. The 0 dB reference is for ±75 kHz deviation at 400 Hz modulation.

Meter Output and Signal-to-Noise vs Tuner Input

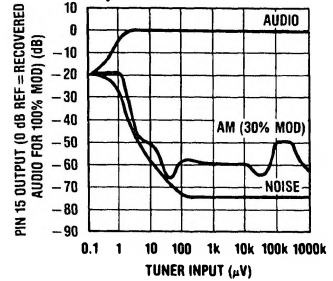


- 3 dB limiting = 0.9 μV
- 30 dB quieting = 1.4 μV
- Level stop/mute threshold = 1.4 μV
- Deviation mute window (-3 dB) = ±45 kHz

Total Harmonic Distortion vs Tuner Input



AM Rejection vs Tuner Input



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## Application Notes

### ADJUSTABLE MUTE/STOP THRESHOLD

The threshold adjustments for the mute and stop functions are controlled by the same pins. Thus, the term mute/stop will be used to designate either function.

The adjustable mute/stop threshold in the LM1865/LM1965/LM2065 allows for user programming of the signal level at which muting or stop indication takes place. The adjustment can be made in two mutually exclusive ways. The first way is to take a voltage divider from the meter output (pin 8) to the off channel mute input (pin 13). When the voltage at pin 13 falls below 0.22V, an internal comparator is tripped causing muted or causing the stop output to go low. Adjustment of the voltage divider ratio changes the signal level at which this happens.

The second method of mute/stop detection as a function of signal level is to use the presence of ultrasonic noise in the recovered audio to trip the internal comparator. As the signal level at the antenna of the radio drops, the amount of noise in the recovered audio, both audible and ultrasonic, increases.

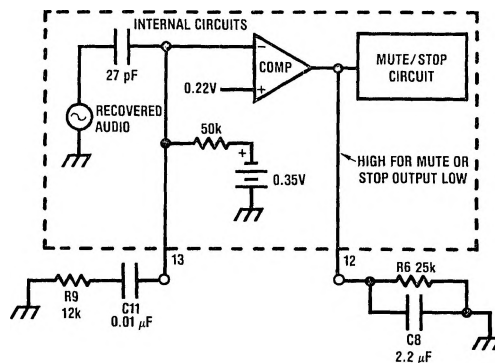
The recovered audio is internally coupled through a high pass filter to pin 13 which is internally biased above the comparator trip point. Large negative-going noise spikes will drive pin 13 below the comparator trip point and cause mute/stop action. A simplified circuit is shown in *Figure 4*.

Since the input to the comparator is noise, the output of the comparator is noise. Consequently, a mute/stop filter on pin 12 is required to convert output noise spikes to an average DC value. This filter is not necessary if pin 13 is driven from the meter.

Adjustment of the mute/stop threshold in the noise mode is accomplished by adjusting the pole of the high pass filter coupled to the comparator input. This is done with a series capacitor/resistor combination, R9 C11, from pin 13 to ground. As the pole is moved higher in frequency (i.e., R9 gets smaller) more ultrasonic noise is required in the recovered audio in order to initiate mute/stop action. This corre-

sponds to a weaker signal at the antenna of the radio. In choosing the correct value for R9 it is important to make sure that recovered audio below 75 kHz is not sufficient to cause mute/stop action. This is because stereo and SCA information are contained in the audio signal up to 75 kHz. Also note that the ultrasonic mute/stop circuit will not operate properly unless a tuner is connected to the IF. This is because, at low signal levels, the noise at the tuner output dominates any noise sources in the IC. Consequently, driving the IC directly with a 50Ω generator is much less noisy than driving the IC with a tuner and therefore not realistic. The RC filter on pin 12 not only filters out noise from the comparator output but controls the "feel" when manually tuning. For example, a very long time constant will cause the mute to remain active if you rapidly tune through valid strong stations and will only release the mute if you slowly tune to a valid station. Conversely, a short time constant will allow the mute to kick in and out as one tunes rapidly through valid stations.

The advantage in using the noise mute/stop approach versus the meter driven approach is that the point at which mute/stop action occurs is directly related to the signal-to-noise ratio in the recovered audio. Furthermore, the mute/stop threshold is not subject to production and temperature variations in the meter output voltage at low signal levels, and thus might be able to be set without a production adjustment of the radio. The noise mute/stop threshold is very insensitive to temperature and gain variations. Proper operation of this circuit requires that the signal level mute/stop threshold be set at a signal level that achieves 45 dB S/N ( $\pm 3$  dB) in mono. in a radio. In an electronically tuned radio, the signal level stop threshold can be set to a much larger level by gain reducing the tuner (ie. pulling the AGC line) in scan mode and then releasing the AGC once the radio stops on a station. In an environment where temperature variations are minimal and manual adjustment of the signal level mute/stop threshold is desired, then the meter driven approach is the best alternative.



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FIGURE 4. Simplified Level Mute/Stop Circuit

## Application Notes (Continued)

### DEVIATION MUTE/STOP

As with the LM3189, the resistor connected between  $V_{REG}$  (pin 9) and the AFT (pin 14) sets the deviation mute/stop window (see Typical Performance Characteristics). The LM1965 was designed with a soft deviation mute. This means that the audio is gradually muted as you off tune from center frequency. Gradually muting avoids the problem of an audio pop which would otherwise occur due to the unavoidable DC voltage shift at the audio output that accompanies the muting action. Capacitor C9 on the AFT pin sets the time constant for the deviation mute/stop independent of the level mute/stop time constant. C9 should be large enough to remove the audio from the AFT. The AFT pulls high at low signal levels if the IF is driven directly from a 50 $\Omega$  generator and not a tuner. This is a result of a loss of signal across the quad coil and a resulting phase shift in the quadrature detector. This phase shift offsets the AFT. With a tuner and sufficient IF gain, at low signal levels there will be enough noise across the quad coil to prevent much of this AFT shift. Thus, care should be taken when adjusting the IF gain (which is done by adjusting the ratio of R3 to R2) to minimize the AFT shift. Grounding pin 16 on the LM1965 will disable the mute function.

### STOP TIME

An electronically tuned radio (ETR) pauses at fixed intervals across the FM band and awaits the stop indication from the LM1865/LM2065. If within a predetermined period of time, no stop indication is forthcoming, the controller circuit concludes that there is no valid station at that frequency and will tune to the next interval. There are several time constants that can affect the amount of time it takes the LM1865/LM2065 to output a valid stop indication on pin 16. In this section each time constant will be discussed.

#### Deviation Stop Time Constant

An offset voltage is generated by the AFT if the LM1865/LM2065 is tuned to either side of a station. Since deviation stop detection in the LM1865/LM2065 is detected by the voltage at pin 14, it is important that this voltage move fast enough to make the deviation stop decision within the time allowed by the controller. The speed at which the voltage at pin 14 moves is governed by the RC time constant, R5 C9. This time constant must be chosen long enough to remove recovered audio from pin 14 and short enough to allow for reasonable stop detection time.

#### Signal Level Stop Using Ultrasonic Noise Detection

As previously mentioned, the R6 C8 time constant on pin 12 is necessary to filter the noise spikes on the output of the internal comparator in the LM1865/LM1965/LM2065. This time constant also determines the level stop time. When the voltage at pin 12 is above a threshold voltage of about 0.6V, the stop output is low. The maximum voltage at pin 12 is about 0.8V. The level stop time is dominated by the amount of time it takes the voltage at pin 12 to fall from 0.8V to

0.6V. The voltage at pin 12 follows an exponential decay with RC time constant given by R6 C8. For example if R6 = 25k and C8 = 2.2  $\mu$ F the stop time is given by

$$t = -(24k)(2.2 \mu F) \ln \left( \frac{0.6}{0.8} \right)$$

which yields  $t = 15$  ms. It should be noted that the 0.6V threshold at pin 12 has a high temperature dependence and can move as much as 100 mV in either direction.

#### Signal Level Stop Using the Meter Output, Pin 8

As mentioned previously, R6 C8 is not necessary when the meter output is used to drive pin 13. Consequently, this time constant is not a factor in determining the stop time. However, the speed at which the meter voltage can move may become important in this regard. This speed is a function of the resistive load on pin 8 and filter capacitance, C5.

#### AGC Time Constant

In tuning from a strong station to a weaker station above the level stop threshold, the AGC voltage will move in order to try to maintain a constant tuner output. The AGC voltage must move sufficiently fast so that the tuner is gain increased to the point that the level stop indicates a valid station. This time constant is controlled by R11 and C13.

#### DISTORTION COMPENSATION CIRCUIT

The quadrature detector of the LM1865/LM1965/LM2065 has been designed with a special circuit that compensates for distortion generated by the non-linear phase characteristic of the quadrature coil. This circuit not only has the effect of reducing distortion, but also desensitizes the distortion as a function of tuning characteristic. As a result, low distortion is achieved with a single tuned quad coil without the need for a double tuned coil which is costly and difficult to adjust on a production basis. The lower distortion has been achieved without any degradation of the noise floor of the audio output. Furthermore, the compensation circuit first-order cancels the effect of quadrature coil Q on distortion.

When measuring the total harmonic distortion (THD) of the LM1865/LM1965/LM2065, it is imperative that a low distortion RF generator be used. In the past it has been possible to cancel out distortion in the generator by adjustment of the quadrature coil. This is because centering the quadrature coil at other than the point of inflection on the S-curve introduces 2nd harmonic distortion which can cancel 2nd harmonic distortion in the generator. Thus low THD numbers may have been obtained wrongly. Large AFT offsets asymmetrical off tuning characteristic, and less than minimum THD will be observed if alignment of the quadrature coil is done with a high distortion RF generator.

Care must also be taken in choosing ceramic filters for the LM1865/LM1965/LM2065. It is important to use filters with good group delay characteristics and wide enough bandwidth to pass enough FM sidebands to achieve low distortion.



## Application Notes (Continued)

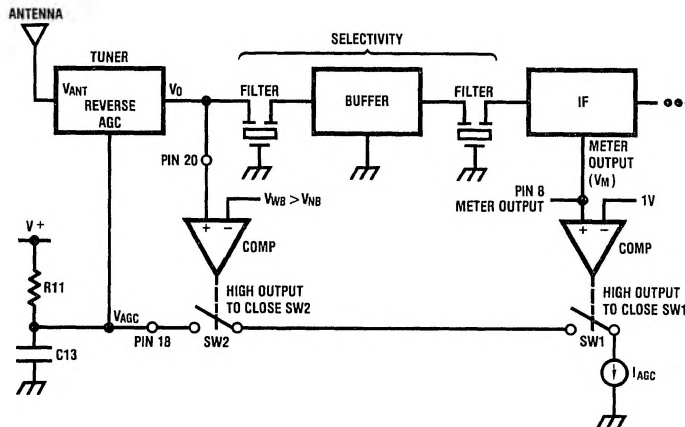
The LM1865/LM1965/LM2065 has been carefully designed to insure low AFT offset current at the point of minimum THD. AFT offset current will cause a non-symmetric deviation mute/stop window about the point of minimum THD. No external AFT offset adjustment should be necessary with the LM1865/LM1965/LM2065. The amount of resistance in series with the 18  $\mu\text{H}$  quadrature coil drive inductor, L1, has a significant effect on the minimum THD. This series resistance is contributed not only by R13 but also by the Q of L1. The Q of L1 should be as high as possible (ie:  $Q > 50$ ) in order to avoid production problems with the Q variation of L1. Once R13 has been optimized for minimum THD, adjustment on a radio by radio basis should be unnecessary.

### DUAL THRESHOLD AGC (AUTOMATIC LOCAL/DISTANCE SWITCH)

There is a well recognized need in the field for gain reducing (AGCing) the front end (tuner) of an FM receiver. This gain reduction is important in preventing overload of the front end which might occur for large signal inputs. Overloading the front end with two out-of-band signals, one channel spacing apart and one channel spacing from center frequency, or two channel spacings apart and two channel spacings from center frequency, will produce a third order intermodulation product ( $\text{IM}_3$ ) which falls inband. This  $\text{IM}_3$  product can completely block out a weaker desired station. The AGC in the LM1865/LM1965/LM2065 has been specially designed to deal with the problem of  $\text{IM}_3$ .

With the LM1865/LM1965/LM2065 system, a low AGC threshold is achieved whenever there are strong out-of-band signals that might generate an interfering  $\text{IM}_3$  product, and a high AGC threshold is achieved if there are no strong out-of-band signals. The high AGC threshold allows the receiver to obtain its best signal-to-noise performance when there is no possibility of an  $\text{IM}_3$  product. The low AGC threshold allows for weaker desired stations to be received without gain-reducing the tuner. It should be noted that when the AGC threshold is set low, there will be a signal-to-noise compromise, but it is assumed that it is more desirable to listen to a slightly noisy station than to listen to an undesired  $\text{IM}_3$  product. The simplified circuit diagram (Figure 5) of the AGC system shows how the dual AGC thresholds are achieved.

$V_m = 1\text{V}$  corresponds to a fixed in-band signal level (defined as  $V_{NB}$ ) at the tuner output.  $V_{NB}$  will be referred to as the "narrow band threshold".  $V_{WB}$  also corresponds to a fixed tuner output which can either be an in-band or out-of-band signal. This fixed tuner output will be called the "wide band threshold". Always  $V_{WB} > V_{NB}$ . R11 and C13 define the AGC time constant. A reverse AGC system is shown. This means that  $V_{AGC}$  decreases to gain-reduce the tuner. The LM1865/LM1965 AGC output is an open-collector current source capable of sinking at least 1 mA. The LM2065 AGC output is also an open collector current source capable of sourcing at least 1 mA. The AGC voltage can move over the full range of the  $V^+$  supply.



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**FIGURE 5. Dual Threshold AGC**

$$I_1 = G_{M1} V_m \text{ only if } V_m > 1\text{V} \\ \text{otherwise } I_1 = 0$$

$$G_{M1}, V_{WB} = \text{constants}$$

$$I_{AGC} = G_{M2} V_0 \text{ where } G_{M2} = I_1/26 \text{ mV and} \\ V_0 > V_{WB} \text{ otherwise } I_{AGC} = 0$$

## Application Notes (Continued)

First examine what happens with a single in-band signal as we vary the strength of this signal. *Figures 6 and 7* illustrate what happens at the tuner and AGC outputs.

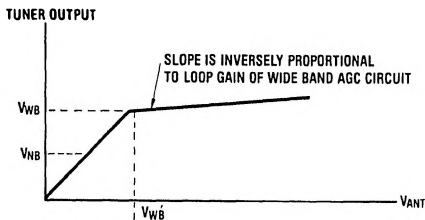


FIGURE 6

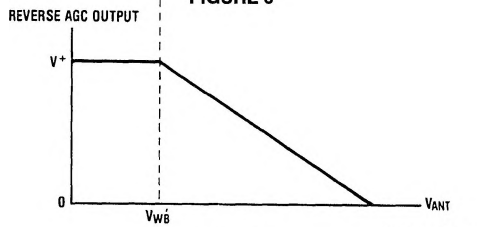


FIGURE 7

In *Figure 7* there is no AGC output until the tuner output equals the wide band threshold. At this point both SW2 and SW1 are closed and the AGC holds the tuner output in *Figure 6* relatively constant.

Another simple case to examine is that of the single out-of-band signal. Here there is no AGC output even if the signal exceeds  $V_{WB}$ . There is no output because the ceramic filters prevent the out-of-band signal from getting to the input of the IF. With no signal at the IF input there is no meter output and SW1 is open, which means No AGC.

*Figures 8 and 9* illustrate what happens at the tuner and AGC outputs when the strength of an in-band signal is varied in the presence of a strong out-of-band signal (i.e., greater than  $V_{WB}$ ) which is held constant at the tuner input. For this example, the in-band signal at the tuner output will be referred to as  $V_D$  (desired signal), and the out-of-band signal as  $V_{UD}$  (undesired signal).

In *Figure 9*, we see that there is no AGC output until the tuner output exceeds the narrow band threshold,  $V_{NB}$ . At this point  $V_m > 1V$  and SW1 closes. Further increase of the desired signal at the tuner input results in an AGC current that tries to hold the desired signal at the tuner output constant. This gain reduction of the tuner forces the undesired signal at the tuner output to fall. At the point that  $V_{UD}$  reaches the wide band threshold, no further gain reduction can occur as  $V_O$  would fall below  $V_{WB}$  (refer to *Figure 5*). At this point, control of the AGC shifts from the meter output (narrow band loop) to the out-of-band signal (wide band loop). Here  $V_{UD}$  is held constant along with the AGC

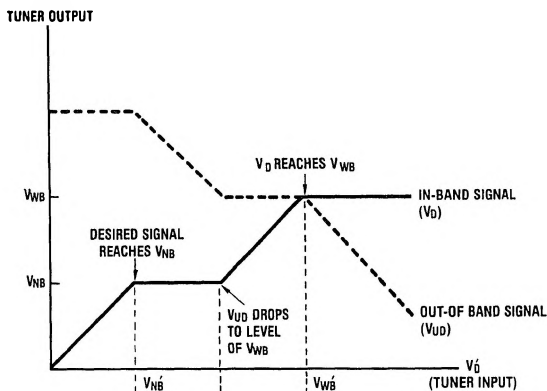
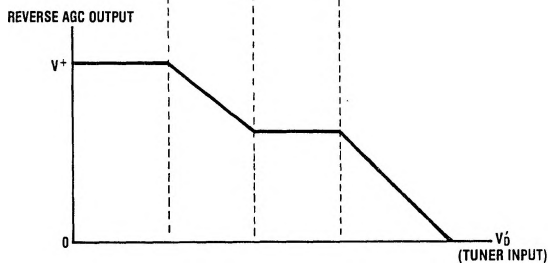


FIGURE 8



Prime indicates referenced to tuner input

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FIGURE 9

## Application Notes (Continued)

voltage, while  $V_D$  is allowed to increase.  $V_D$  will increase until it reaches the level of the wide band threshold at the tuner output. When this occurs  $V_{UD}$  is no longer needed to keep  $V_o > V_{WB}$  as  $V_D$  takes over the job. Thus  $V_{UD}$  will drop as the amount of AGC increases, while  $V_D$  is held constant by the AGC.

When compared to the simple case of a single in-band signal, we see that because of the presence of a strong out-of-band signal, AGC action has occurred earlier. For the simple case, AGC started when  $V_D \geq V_{WB}$ . For the two signal case above, AGC started when  $V_D \geq V_{NB}$ . Thus, the LM1865/LM1965/LM2065 achieves an early AGC when there are strong adjacent channels that might cause  $IM_3$ , and a later AGC when these signals aren't present.

For the range of signal levels that the tuner was gain-reduced and  $V_D < V_{WB}$  there was loss in signal-to-noise in the recovered audio as compared to the case where there was no gain reduction in this interval. *Note, however, that the tuner is not desensitized by the AGC to weak desired stations below the narrow band threshold.*

## NARROW BAND AGC THRESHOLD ADJUSTMENT

Both the narrow band and wide band AGC thresholds are user adjustable. This allows the user to optimize the AGC response to a given tuner. Referring to *Figure 5*, when the meter output exceeds 1V a comparator closes SW1. A simplified circuit diagram of this comparator is shown in *Figure 10*.

The 1K resistor in series with pin 8 allows for an upward adjustment of the narrow band threshold. This is accomplished by externally loading pin 8 with a resistor. *Figure 11* illustrates how this adjustment takes place.

From *Figure 11* it is apparent that loading the meter output not only moves the narrow band threshold, but also decreases the meter output for a given input.

In general one chooses the narrow band threshold based on what signal-to-noise compromise is considered acceptable.

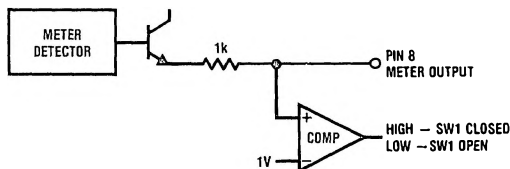


FIGURE 10. Narrow Band Threshold Circuit

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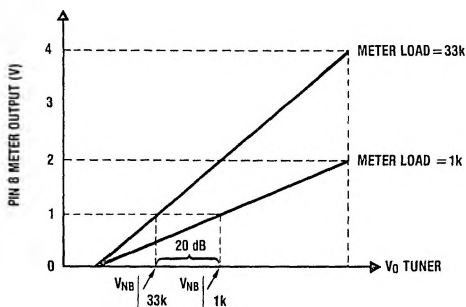


FIGURE 11. Affect of Meter Load on Narrow Band Threshold

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## Application Notes (Continued)

### WIDE BAND AGC THRESHOLD ADJUSTMENT

There are a number of criteria that determine where the wide band threshold should be set. If the threshold is set too high, protection against  $IM_3$  will be lost. If the threshold is set too low, the front end, under certain input conditions, may be needlessly gain-reduced, sacrificing signal-to-noise performance. Ideally, the wide band threshold should be set to a level that will insure AGC operation whenever there are out-of-band signals strong enough to generate an  $IM_3$  product of sufficient magnitude to exceed the narrow band threshold. Ideally, this level should be high enough to allow for a single in-band desired station to AGC the tuner, only after the maximum signal-to-noise has been achieved.

In order to insure that the wide band loop is activated whenever the  $IM_3$  exceeds the narrow band threshold,  $V_{NB}$ , determine the minimum signal levels for two out-of-band signals necessary to produce an  $IM_3$  equal to  $V_{NB}$ . Then, arrange for the wide band loop to be activated whenever the tuner output exceeds the rms sum of these signals. There are many combinations of two out-of-band signals that will produce an  $IM_3$  of a given level. However, there is only one combination whose rms sum is a minimum at the tuner output.  $IM_3$  at the tuner output is given according to the equation:

$$IM_3 = aV_{UD1}^2 V_{UD2} \text{ (assuming no gain reduction)} \quad (1)$$

where  $a$  = constant dependent on the tuner;

$V_{UD1}$  = out-of-band signal 400 kHz from center frequency, applied to tuner input;

$V_{UD2}$  = out-of-band signal 800 kHz from center frequency and 400 kHz away from  $V_{UD1}$ , applied to tuner input.

In general, due to tuned circuits within the tuner, the tuner gain is not constant with frequency. Thus, if the tuner is kept fixed at one frequency while the input frequency is changed, the output level will not remain constant. *Figure 12* illustrates this.

It can be shown that for a given  $IM_3$ , the combination of  $V_{UD1}$  and  $V_{UD2}$  that produces the smallest rms sum at the tuner output is given by the equations:

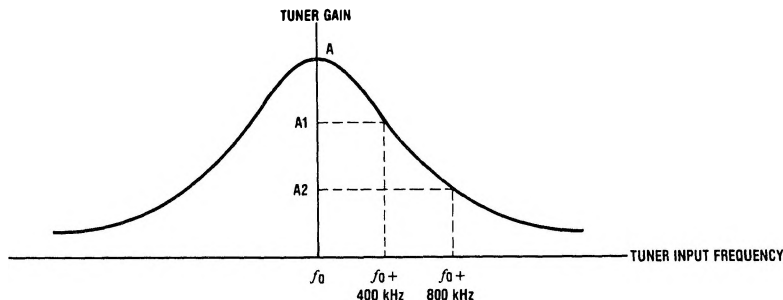
$$V_{UD1} = 1.12 \left( \frac{A_2}{A_1} \frac{IM_3}{a} \right)^{1/3} \quad (2)$$

$$V_{UD2} = 0.794 \left( \frac{A_1^2}{A_2^2} \frac{IM_3}{a} \right)^{1/3} \quad (3)$$

Therefore, in order to guarantee that the AGC will be keyed for an  $IM_3 = V_{NB}$  we need only satisfy the condition:

$$V_{WB} \leq \sqrt{V_{NB}^2 + \left[ (A_1) (1.12) \left( \frac{A_2 V_{NB}}{A_1 a} \right)^{1/3} \right]^2 + \left[ A_2 (0.794) \left( \frac{A_1^2 V_{NB}}{A_2^2 a} \right)^{1/3} \right]^2} \quad (4)$$

The right hand term of equation (4) defines an upper limit for  $V_{WB}$  called  $V_{WBUL}$ .  $V_{WBUL}$  is the rms sum of all the signals at the tuner output for two out-of-band signals,  $V_{UD1}$  and  $V_{UD2}$  [as expressed in equations (2) and (3)], applied to the tuner input.



Define  $A$  = tuner gain at center frequency

$A_1$  = tuner gain at  $f_0 + 400$  kHz

$A_2$  = tuner gain at  $f_0 + 800$  kHz

FIGURE 12

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## Application Notes (Continued)

In order to make the calculation in equation (4), the constants  $a$ ,  $A1$ ,  $A2$  must first be determined. This is done by the following procedure:

1. Connect together two RF generators and apply them to the tuner input. Since the generators will terminate each other, remove the 50 $\Omega$  termination at the tuner input.
2. Connect a spectrum analyzer to the tuner output. Most spectrum analyzers have 50 $\Omega$  input impedances. To make sure that this impedance does not load the tuner output use a FET probe connected to the spectrum analyzer. The tuner output should be terminated with a ceramic filter.
3. Disconnect the AGC line to the tuner. Make sure that the tuner is not gain-reduced.
4. Adjust the two RF generators for about 1 mV input and to frequencies 400 kHz and 800 kHz away from center frequency (Figure 13).
5. Note the three output levels in volts.
6. Knowing the tuner input levels for  $V_{UD1}$  and  $V_{UD2}$  and the resulting  $IM_3$  just measured, "a" is calculated from the formula:

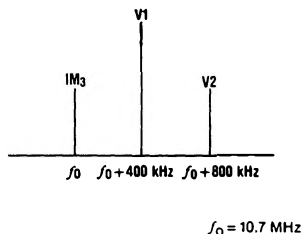
$$a = \frac{IM_3}{V_{UD1}^2 V_{UD2}} \quad (5)$$

where all levels are in volts rms. A typical value for "a" might be  $2 \times 10^6$ .

7.  $A1$  and  $A2$  are calculated according to the following formulas

$$A1 = \frac{V1}{V_{IN} \sqrt{f_o + 400 \text{ kHz}}} \quad (6)$$

$$A2 = \frac{V2}{V_{IN} \sqrt{f_o + 800 \text{ kHz}}} \quad (7)$$



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FIGURE 13. Spectrum Analyzer Display of Tuner Output

If the wide band threshold was set to  $V_{WBUL}$ , then when a single in-band station reached the level  $V_{WBUL}$  at the tuner output, AGC action would start to take place. For this reason it is hoped that  $V_{WBUL}$  is above the level that will allow for maximum signal-to-noise. If, however, this is not the case, consideration might be given to improving the inter-modulation performance of the tuner.

The lower limit for  $V_{WB}$  is the minimum tuner output that achieves the best possible signal-to-noise ratio in the recovered audio. In general, it is desirable to set  $V_{WB}$  closer to the upper limit rather than the lower limit. This is done to prevent AGC action within the narrow band loop except when there is a possibility of an  $IM_3$  greater than  $V_{NB}$ .

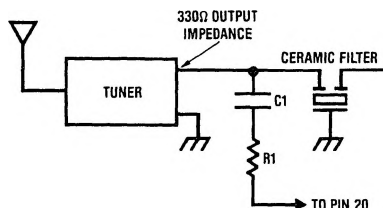
The wide band threshold at the pin 20 input to the LM1865/LM1965/LM2065 is fixed at 12 mVrms. Generally speaking, if pin 20 were driven directly from the tuner output,  $V_{WB}$  would be too low. Therefore, in general, pin 20 is not connected directly to the tuner output. Instead the tuner output is attenuated and then applied to pin 20. Increasing attenuation increases the wide band threshold,  $V_{WB}$ .

Pin 20 has an input impedance at 10.7 MHz that can be modeled as a 500 $\Omega$  resistor in series with a 19 pF capacitor, giving a total impedance of 940 $\Omega$   $\angle$  -58°. Thus an easy way to attenuate the input to pin 20 is with the arrangement shown in Figure 14.

Notice that pin 20 must be AC coupled to the tuner output and that C1 is a bypass capacitor. R1 adjusts the amount of attenuation to pin 20. The wide band threshold will roughly increase by a factor of  $(R1 + 940\Omega)/940\Omega$ .

### AGC CIRCUIT USED AS A CONVENTIONAL AGC

If for some reason the dual AGC thresholds are not desired, it is easy to use the LM1865/LM1965/LM2065 as a more conventional LM3189 type of AGC. This is accomplished by AC coupling the pin 20 input after the ceramic filters rather than before the filters. Thus, as with the LM3189, only in-band signals will be able to activate the AGC.



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FIGURE 14. Wide Band Threshold Adjustment

