DS8911 AM/FM/TV Sound Up-Conversion Frequency Synthesizer

National Semiconductor
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INTRODUCTION

This application note describes an AM/FM radio implemented using the DS8911 Up-Conversion Frequency Synthesizer. This synthesizer was designed to utilize up-conversion techniques to reduce the manufacturing costs and labor requirements associated with alignment of an AM radio front end.

The conventional high performance AM radio requires at least three tuned circuits for AM reception (see *Figure 1*). These tuned circuits include 3 varactor diodes which must be matched to ensure tracking over a wide Local Oscillator (LO) operating range. The cost of these matched varactors and labor associated with alignment of the three stages is significant.

The three circuits are:

a. RF antenna input
b. RF amplifier output
c. Local oscillator

THE UP-CONVERSION AM RADIO USING THE DS8911

In an up-conversion AM radio the local oscillator and first IF frequency are chosen to be much higher in frequency than the received signal. This totally eliminates image problems since the image is far above the band of interest. In this application an IF of 11.55 MHz was chosen. This enables the RF front end to be untuned. A simple low pass filter is included to roll off frequencies above 2 MHz. The first mixer in an up-conversion design is subjected to the entire AM band and thus a very high dynamic range mixer (provided as part of the DS8911) is essential to prevent overload due to strong signals. *Figure 2* shows the block diagram of the radio using an up-conversion scheme. Notice the three AM tuned stages mentioned in the conventional down-conversion scheme have been eliminated.

Note the dramatic simplification summarized below:

a. Untuned AM RF amplifier
b. One VCO internally generates the LO for both AM and FM modes
c. A common AM/FM mixer
d. Reduced number of tuning and tracking adjustments

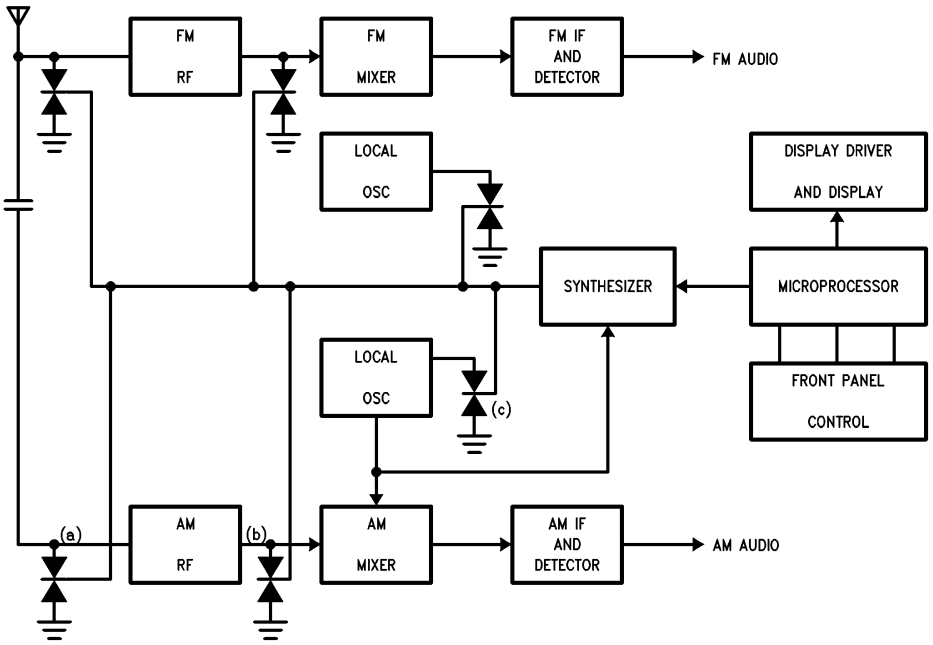

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FIGURE 1. Conventional Electronically Tuned Radio

  RRD-B30M105/Printed in U. S. A.

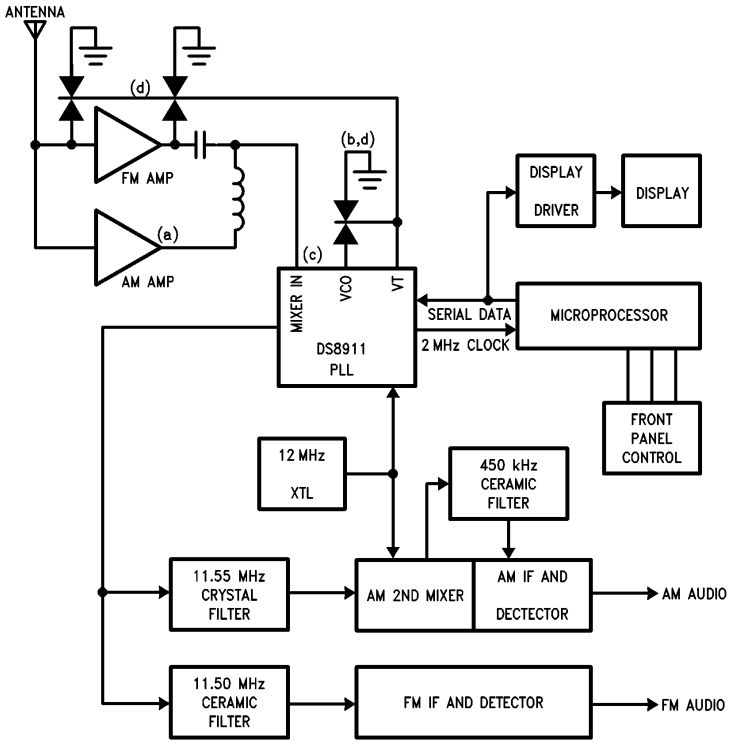

FIGURE 2. Up-Conversion Electronically Tuned Radio

THE DS8911 IN AN ACTUAL RECEIVER APPLICATION

Shown below is a block diagram of the DS8911 demonstration radio.

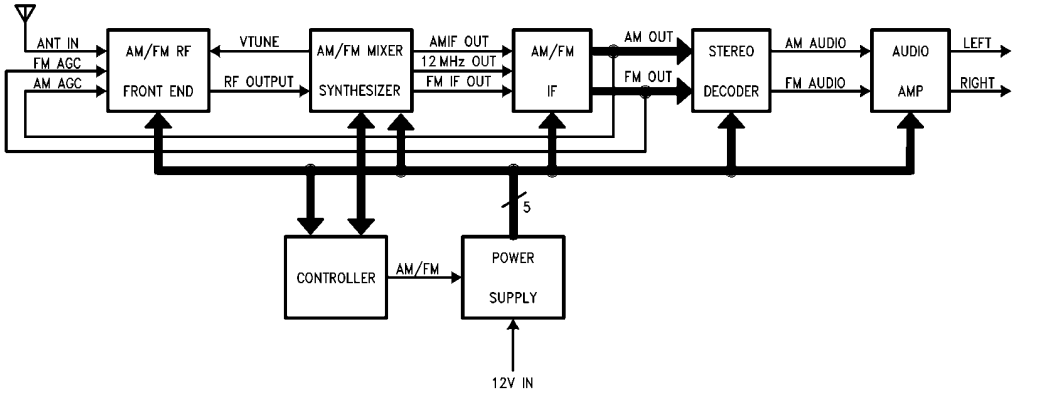

FIGURE 3. Block Diagram of DS8911 Up-Conversion Radio

THE AM AND FM FRONT ENDS

The AM RF amplifier, shown in *Figure 4,* is an untuned JFET input cascode RF amplifier. With the exception of there being no tuned circuits, this is a standard configuration. The output of the cascode amplifier, Q1 and Q2, is further amplified by Q3, which in turn drives a low impedance ($\approx 50\Omega$) wide band transformer, T1. Transformer T1 provides a 2 to 1 impedance step down to drive the differential inputs of the DS8911. Note that C7 and L2 perform a low pass function to limit the response of the RF amp to about 2 MHz. Q10 is connected directly across the antenna input and is activated by the AGC circuit to limit very large received signals.

The typical gain of the AM RF block is 20 dB (antenna to Q3 collector). Most of this gain is lost in the low pass filter and wide-band transformer, T1. The net gain from antenna to the input of the DS8911 is about 8 dB.

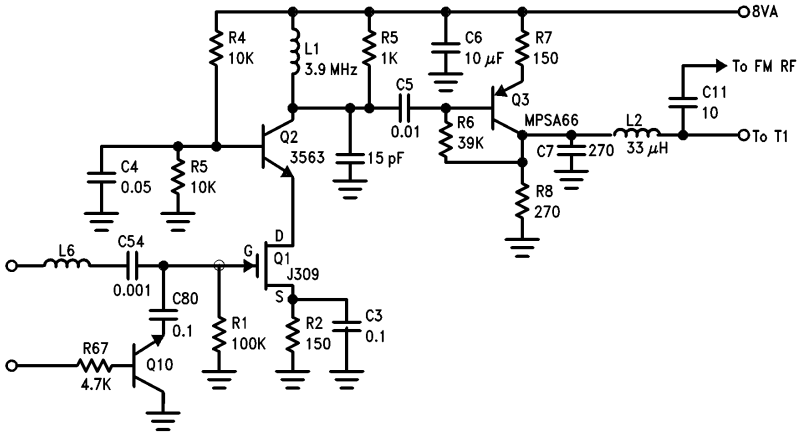

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FIGURE 4. DS8911 Untuned AM RF Front End

The FM RF amplifier is shown in *Figure 5.* It is of conventional design, using two varactor diodes, D1 and D2, for tuning. These diodes and the LO varactor, D1, are driven directly by the DS8911 Mixer/Synthesizer's tuning voltage output (OPAMP OUT).

Note that the wide-band transformer, T1, shown in *Figure 6,* serves as both the AM and FM differential input for the DS8911 mixer. C11 and L2 *(Figure 4),* are used as isolating devices between the AM and FM front ends.

AGC for the FM RF is applied to the second gate of the dual gate mosfet, Q7 *(Figure 5)*. To insure pinch off action during AGC, R68 biases the source of Q7 so that the source cannot drop below about 650 mV. Note that R49 is used in the drain of Q7. This is designed to limit gain and add circuit stability. The approximate gain of the FM RF amplifier is 10 dB.

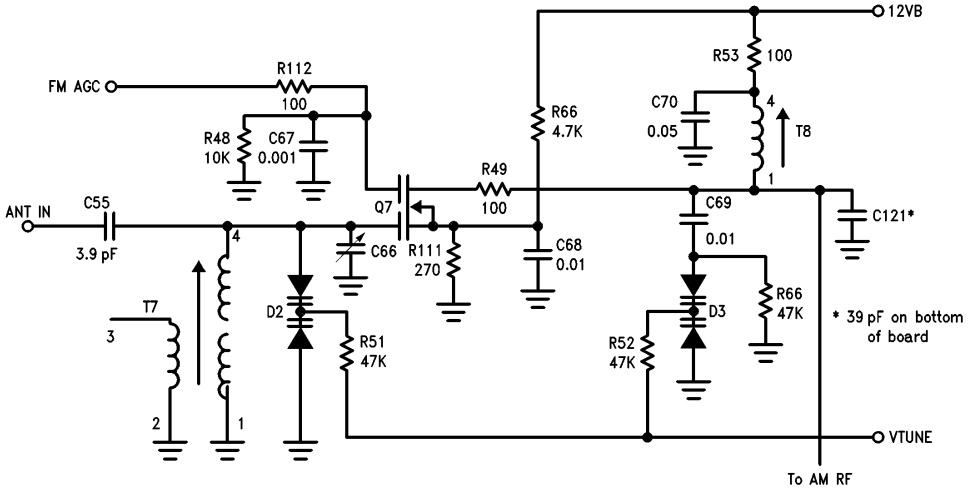

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FIGURE 5. FM RF Front End

THE DS8911 MIXER AND IF FILTER SECTION

A mixer is provided on the DS8911 IC for both the FM conversion to 11.50 MHz and the AM first conversion to 11.55 MHz. The 2nd AM conversion to 450 kHz is provided by the mixer within the AM IF IC. If other partitioning constraints require that the first mixer be external to the DS8911, the RF inputs of the mixer can be de-biased which results in passing the internally generated LO signal to the mixer output pins.

The DS9811 Mixer/Synthesizer section is shown in *Figure 6.*

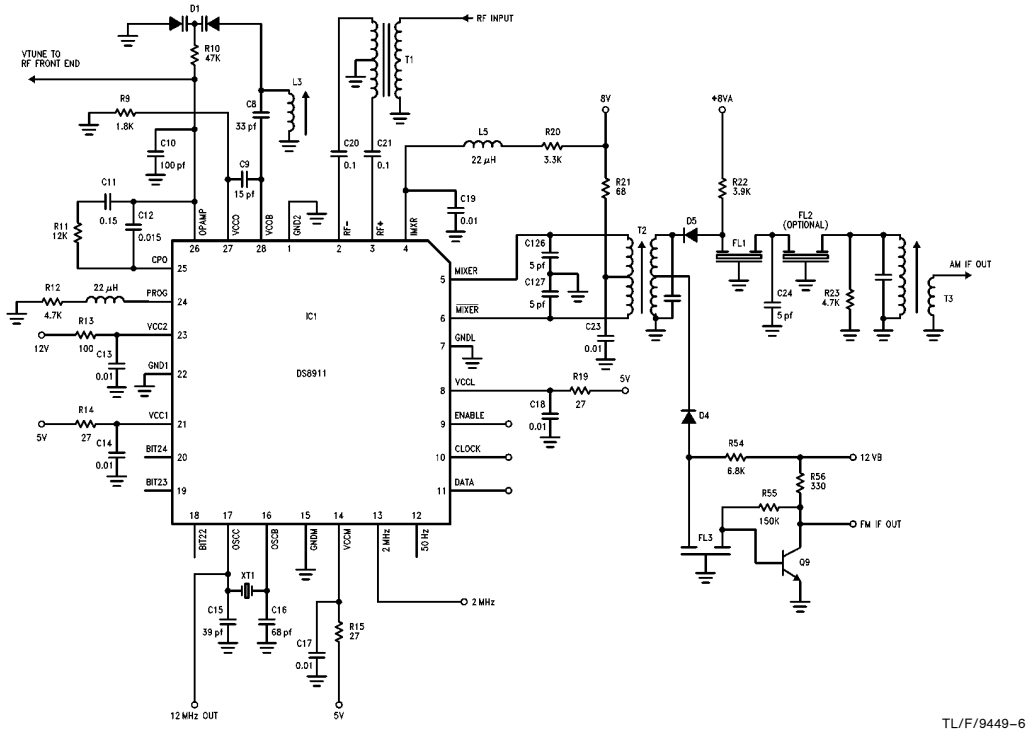

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FIGURE 6. DS8911 Mixer/Synthesizer Section

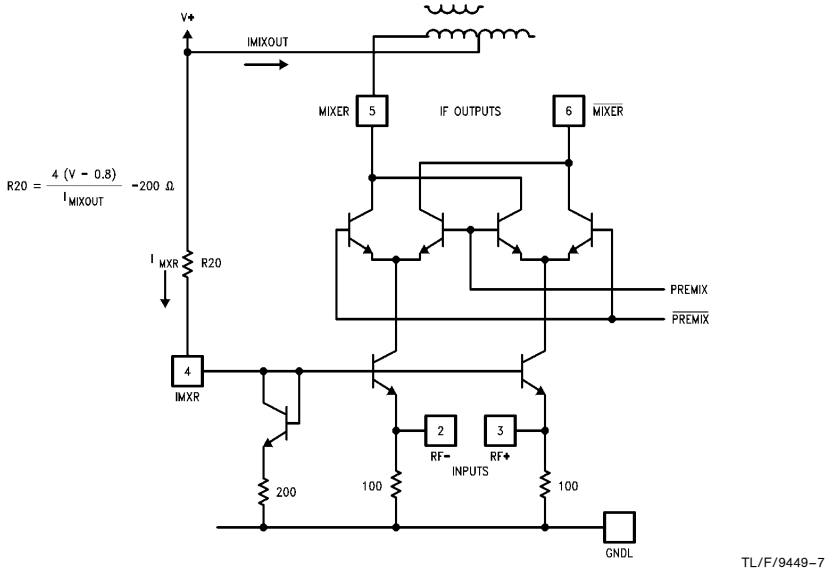

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FIGURE 7. Mixer Bias Circuitry

The DS8911 double balanced mixer is differentially driven by center-tapped T1 into the RF+ and RF− inputs. These are emitter inputs with an approximate impedance of 25Ω.

Current through the double balanced mixer is set by R20, shown in *Figure 7.* The total bias current through the sum of the mixer transistors whose collectors are at $I_{\overline{MIXER}}$ (pin 5) and I_{MIXER} (pin 6), is four times the current set by R20.

$$(I_{MIXER} + I_{\overline{MIXER}}) = 4 \times I_{MXR}$$

A simple equation for calculating the value of R20 is shown in *Figure 7.* The mixer current in this evaluation board is set at 8 mA.

The local oscillator signals used for AM and FM tuning are derived from a single VCO within the DS8911. This VCO's range is from 98 to 120 MHz. In the AM mode this VCO is divided by ten to become the first LO input for the DS8911 mixer. The VCO frequency is set by the external inductor L3 and varactor D1 (see *Figure 6*). Inputs VCOE and VCOB form a Colpitts oscillator with the external components mentioned above. The VCO is capable of operating within the range of 40 to 225 MHz. However, most varactors operate in an approximately 2.5 to 1 capacitance range. At best, this translates to a 1.58 to 1 frequency range ($f = \frac{1}{2}\pi\sqrt{LC}$). At FM frequencies using MV104 varactor diodes, it is possible to tune over a 25 MHz band. When the DS8911 is switched into the AM mode, the same VCO is used, except it is internally divided by ten. This then gives us a 2.5 MHz tuning range which is sufficient to cover the AM band including LW for European applications. It should be noted that when dividing the VCO by ten we increase the tuning resolution by ten. For example, when the VCO is tuned with a 10 kHz resolution, the divided by ten AM LO signal has a 1 kHz tuning resolution.

The DS8911 incorporates a zero deadband charge pump circuit in the phase detector portion of the internal PLL. This results in a VCO that is very stable, and has very low phase noise. This is particularly advantageous when considering AM stereo reception.

DS8911 IF FILTERS

Referring to *Figure 6,* the output of the DS8911 mixer is a differential output, MIXER, $\overline{MIXER}$; pins 5 and 6 respectively. This output is applied to the center-tapped primary of T2, the mixer output transformer, which is tuned to 11.55 MHz.

The AM IF frequency was chosen to be 11.55 MHz so that it would mix directly with the 12 MHz clock to produce a second IF frequency of 450 kHz. The FM IF frequency was chosen to be 11.50 MHz to enable the use of a common tuned 1st IF transformer (T2) for both AM and FM.

A low impedance tap on the secondary of T2 is used to drive FL3 and subsequent buffer circuitry which is fed to the FM IF section. Both FL3 and FL4 are 11.50 MHz ceramic resonators. The higher impedance portion of T2's secondary drives FL1 in series with optional FL2 which form the primary AM filtering. These are 11.55 MHz crystal filters with a 6 dB bandwidth of 7.5 kHz. Using FL1 alone is quite satisfactory, however steeper selectivity skirts are possible if FL2 is included. When both FL1 and FL2 are used, they must be a matched set. The AM IF filter section is interfaced to the AM IF section by transformer T3, shown in *Figure 6.*

THE AM IF SECTION

The AM IF section of the DS8911 evaluation board is implemented using a conventional fully integrated AM radio chip, the SANYO LA1130. See *Figure 8* for schematic of the AM IF section. This device is used in this configuration to receive the modulated AM carrier signal at 11.55 MHz, downconvert it to 450 kHz, and decode the AM modulation. The LO input signal for the LA1130 is provided from the DS8911's 12 MHz crystal oscillator. This LO signal is injected into the OSC pin (pin 4). The low level 11.55 MHz IF signal from the crystal filter is injected into the RF INPUT (pin 2). The RF OUTPUT (pin 5) is tuned to 11.55 MHz with T4 and applied to the second MIXER INPUT (pin 6). Transformers T5 and T6 are tuned to 450 kHz.

It should be noted that T4 could be replaced by a ceramic resonator centered around 11.50 to 11.55 MHz with a bandwidth of several hundred kHz. Transformer T5 could be eliminated and T6 replaced with a 450 kHz resonator to produce a minimum tuned circuit design.

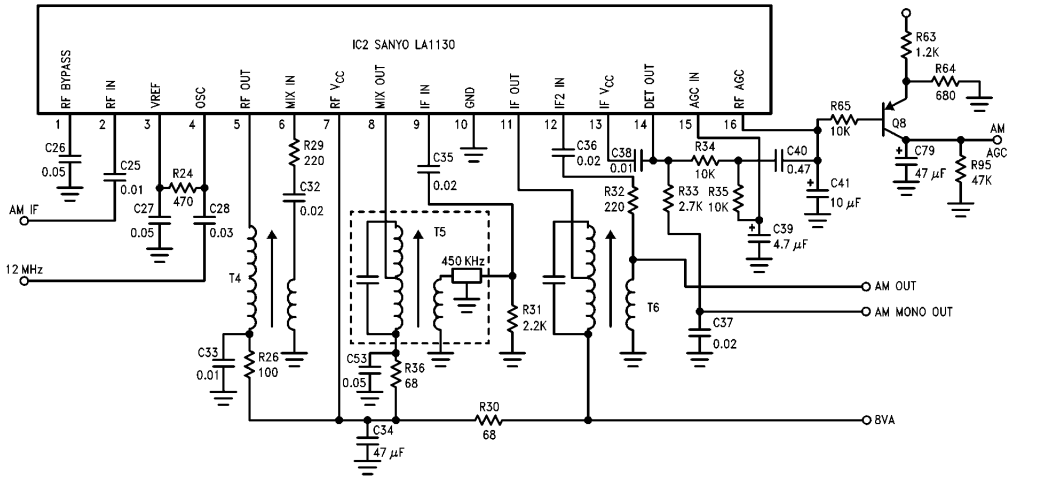

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FIGURE 8. AM IF Circuitry

Detected audio is available at pin 14 (Mono AM out test point). AGC is generated internal to the LA1130, buffered by Q8 and applied to Q10, located in the AM front end.

THE FM IF SECTION

The FM IF filtering is done by FL3 *(Figure 6)* and FL4 *(Figure 9)* which precede the IF amplifier chip IC6, an LM3089. FM quadrature detection is done on chip. External inductor T9 is adjusted for correct FM demodulation. Audio output is made available on pin 6 (FM mono out test point). This is fed to the stereo decoder IC8. *(Figure 11)*

THE STEREO DECODER SECTION

The stereo decoders are a standard configuration with their outputs resistively summed into the dual volume control potentiometer, R_{vol}.

Device IC7, shown in *Figure 10,* is a Motorola MC13020P, an AM stereo decoder designed to decode the C-Quam AM stereo format. Because this chip needs a relatively high level 450 kHz IF signal to operate, transistors Q4 and Q5 boost the IF signal from T6 and apply it to pin 3 of IC7.

The FM stereo decoder, shown in *Figure 11,* is IC8, an LM1800. This device performs the FM stereo multiplex decoding. This circuit is standard and used in numerous consumer applications, therefore is mentioned only briefly.

The audio output section, shown in *Figure 12,* consists of two LM386 devices, IC3 and IC11. These are used simply to drive a pair of monitor loud speakers. No special de-emphasis of the audio has been done in this evaluation board. This should be taken into account if performance measurements are done on this board.

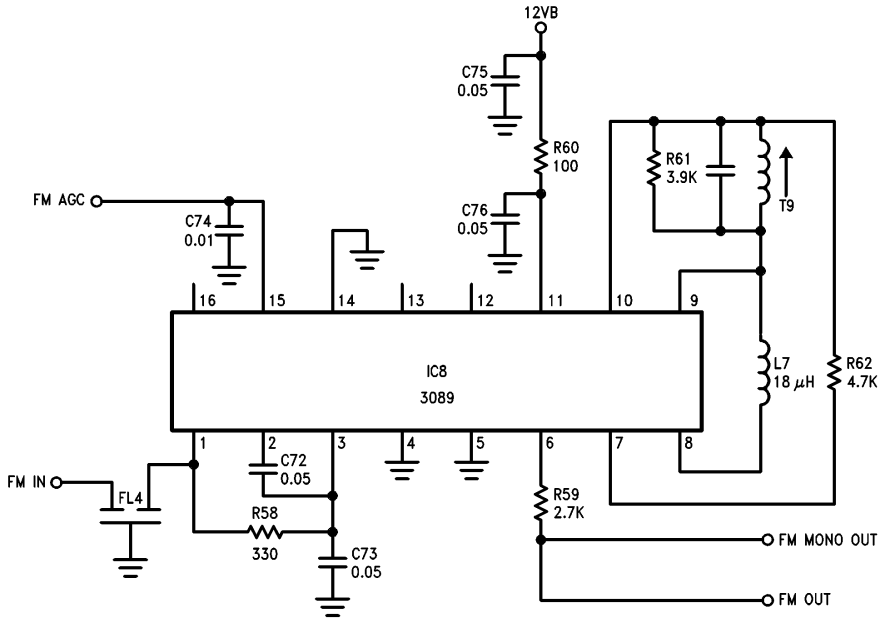

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FIGURE 9. FM IF Circuitry

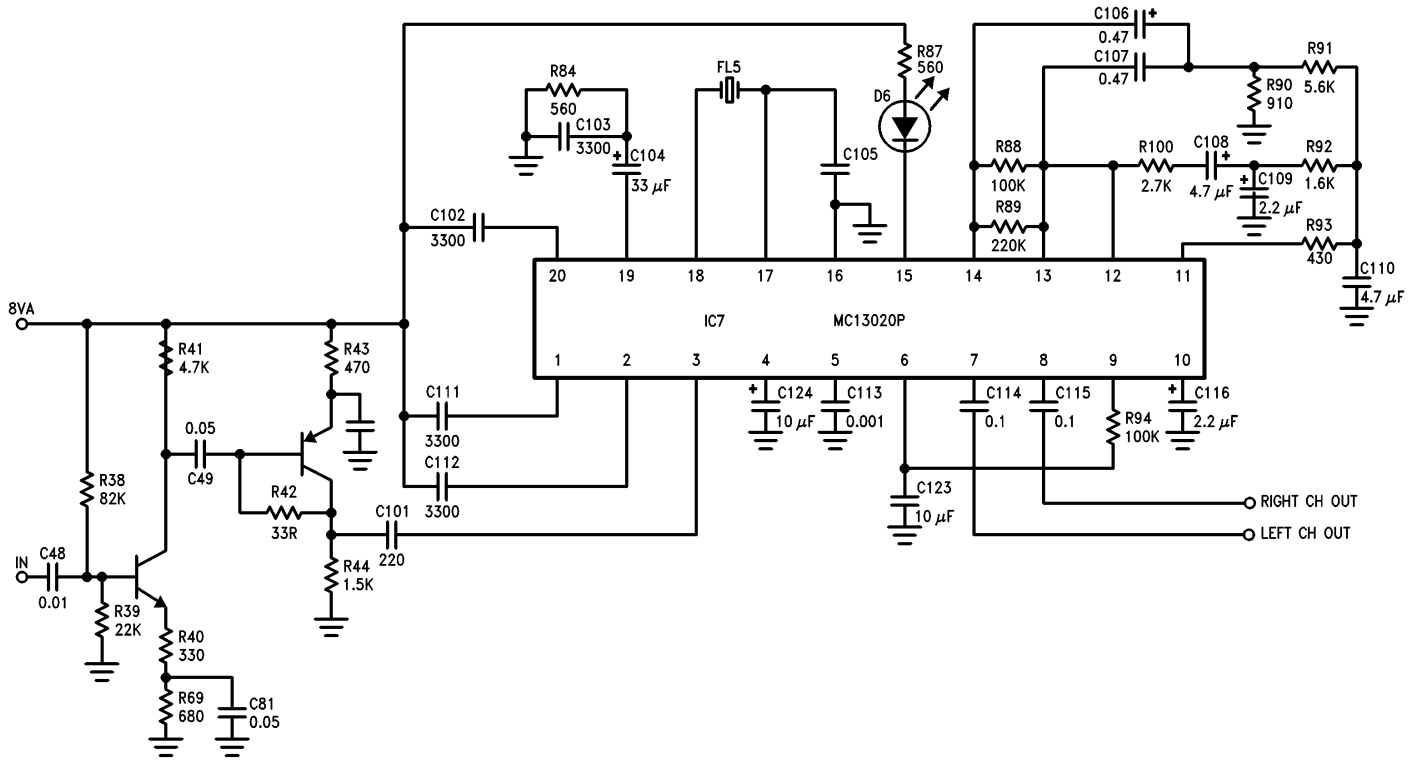

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FIGURE 10. AM Stereo Decoder

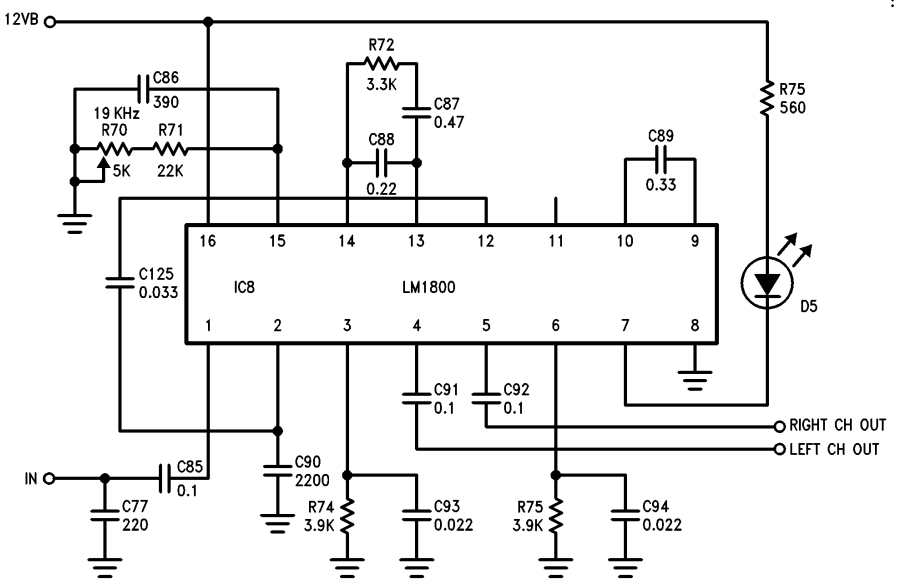

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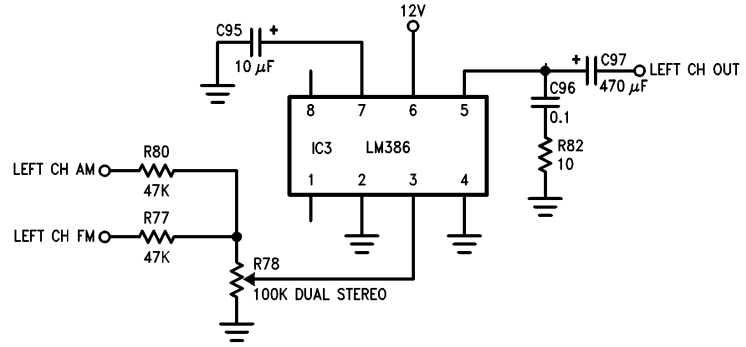
FIGURE 11. FM Stereo Decoder



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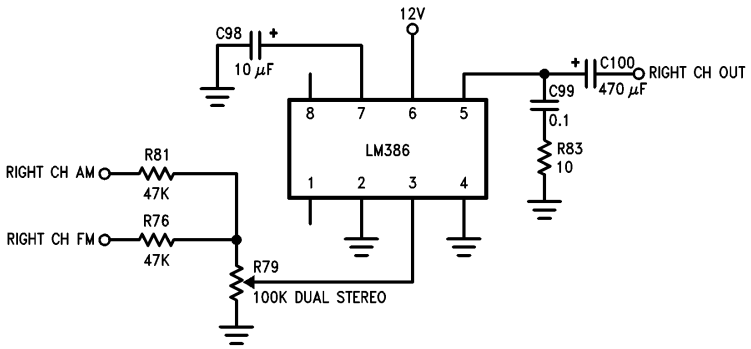

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FIGURE 12. DS8911 Audio Output Circuitry

POWER SUPPLIES

The evaluation board is designed for 12 VdC nominal operation. The power to various sections is controlled by the microcontroller via Q11, Q12, Q13, and Q14 shown in *Figure 13*. On board regulation is provided by IC4, and 8V regulator (used for the signal circuits), and IC5, a 5V regulator (used for the logic circuits). The 12V power is used to operate the rest of the circuitry. No provisions have been made on the board for automobile load dump protection.

APPENDIX

Operating instructions for the DS8911 Application Board

The DS8911 AM/FM radio application board contains a built-in COPS controller which is programmed to send a 24-bit serial data stream to the DS8911 each time a key is pressed on the 4 by 4 keypad. Additionally, new data is sent to the display.

Power up.

Upon power up the radio will tune 98.5 MHz in the FM band. The store keys are preset to tune this frequency in the FM band and 810 kHz in the AM band.

Key Functions.

AM/FM: This key switches between the AM and FM bands. If the key is pressed while in FM, the station is first stored internally and then the band is changed to AM, recalling the last station played.

Note: An ''A'' will appear in the left digit location on the display while in the AM band, and no letter will appear for the FM band.

Tune up (↑), tune down (↓): Steps the tuned frequency by one reference increment at each key stroke.

Fast tune up (↑ ↑), tune down (↓ ↓): Holding this key down steps the frequency up or down repetitively for speedy tuning. There are upper and lower tuning limits which vary according to what reference frequency the DS8911 is using.

STO 1/2/3: A station may be stored by pressing the STO key and then the desired store location 1, 2 or 3 . An ''S'' will show up in the left digit space prompting the user for a store location.

A station may be recalled by directly pressing the store 1, 2 or 3 location. FM stations will be recalled while in the FM band and AM stations will be recalled while in the AM band.

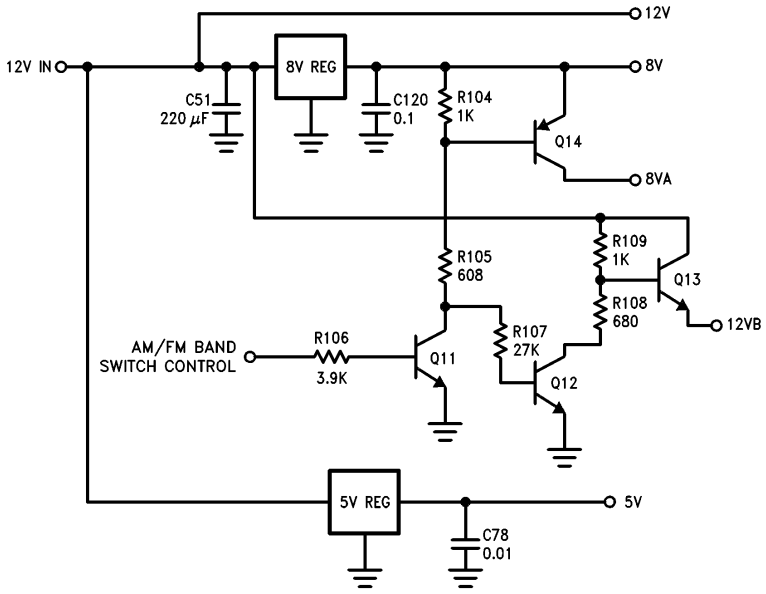

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FIGURE 13. Power Supply Circuitry

Column	Row	Function
M	D	ST0
N	D	1
G	D	3
F	D	3
M	E	AMFM
N	E	LO
G	E	T/M
F	E	REF
M	P	—
N	P	B22
G	P	B23
F	P	B24
M	Q	STEP UP
N	Q	SCAN UP
G	Q	SCAN DOWN
F	Q	STEP DOWN

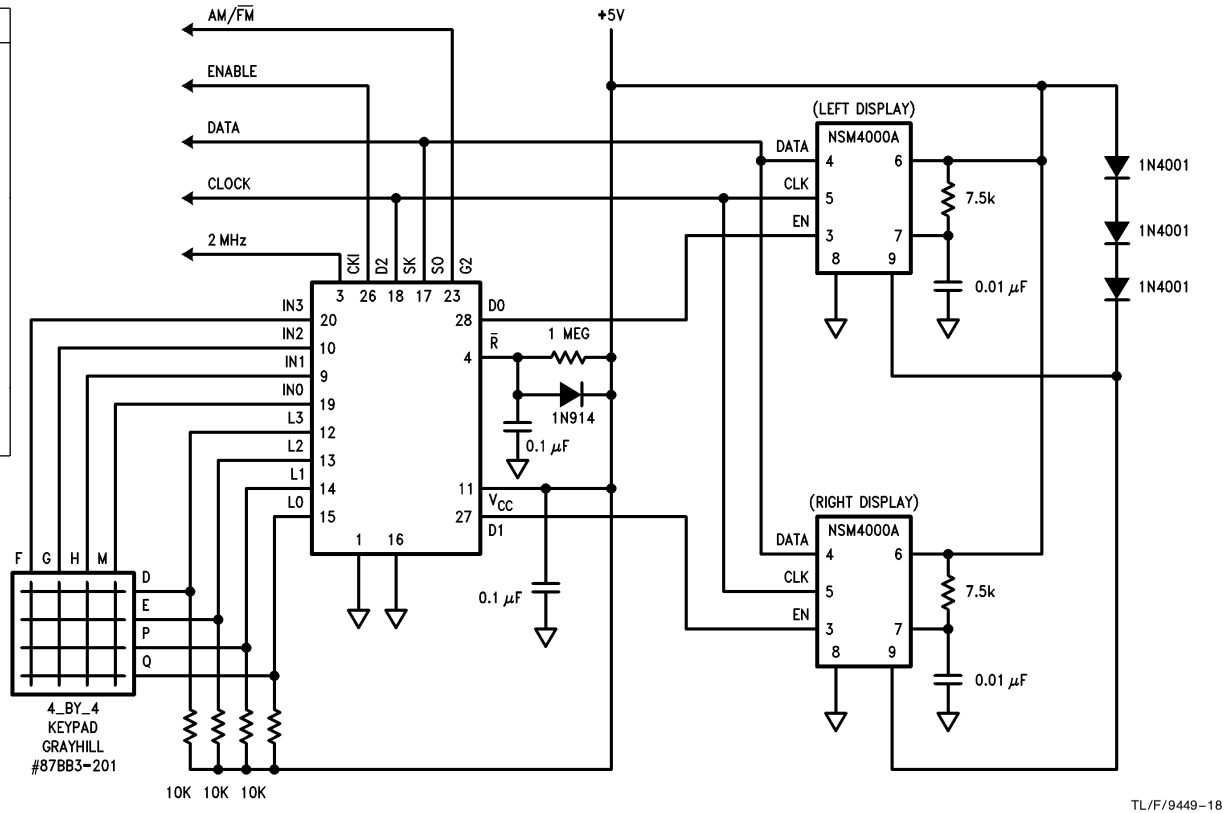

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FIGURE 14. Microprocessor Control and Display Section

LO: The LO key will display the local oscillator frequency that corresponds to the present tuned frequency. The LO frequency displays for a few seconds and then the tuned frequency returns.

TEST MODE: This key allows the user to choose between mode 0, 1, 2 or 3. Each time the key is pressed the test mode will rotate and display the new mode for a few seconds before the tuned frequency reappears. A keypress will not be recognized until the tuned frequency reappears. The system powers up in test mode 0.

REF: This key allows the user to change the reference frequency used by the DS8911. Each keypress rotates the reference frequency from 100 kHz to 10 kHz, 10 kHz to 12.5 kHz, 12.5 kHz to 25 kHz or 25 kHz to 100 kHz depending where it started. The tuned frequency will be recalculated using the new reference frequency and displayed. If the tuned frequency is too high or low, a multiple or a non-integer of the new reference frequency, the program will automatically rotate to the next legal reference frequency, display it for a few seconds, and then return to displaying the tuned frequency. The system powers up in the 100 kHz mode.

BIT 22, 23, 24: Each of these keys changes the high or low state of bit 22, 23 and 24 in the serial data stream to the DS8911. The bits power up low and may be changed high independently by pressing the appropriate key. The display will then show the status of all three bits in the right three digit spots.

Example: Bit 23 high, bit 22 and 24 low. = | 0 | 1 | 0 |

ALIGNMENT

1. In FM mode tune to 98.5 MHz. Adjust L3 while monitoring DC voltage on OP AMP, pin 26 of IC1. Adjust L3 for a reading of 3.4 Vdc.
2. Switch to AM mode. Set generator for 810 kHz, 30% modulation, 400 Hz. RF level: 100 μV. Use 40 pF dummy antenna.
3. Adjust T2, T3, T4, T5, T6 for maximum sensitivity as measured at speaker output using suitable AC voltmeter.

Note: As signal strength increases with alignment, appropriately reduce the RF output of signal generator.

4. Switch to FM mode and tune to 98.5 MHz. Set FM generator to 98.5 MHz. Set RF output to 100 μV, modulation 400 Hz, deviation 22.5 kHz. Use 50Ω termination on antenna input.
5. Adjust T9 for maximum recovered audio and mininum distortion.
6. Adjust T7 and T8 for maximum sensitivity. Reduce RF level of generator as needed.
7. Tune to stereo FM station. Adjust R70 for D5 ''0n.'' 100 μV, modulation 400 Hz, deviation 22.5 kHz. Use 50Ω termination on antenna input.
5. Adjust T9 for maximum recovered audio and minimum distortion.
6. Adjust T7 and T8 for maximum sensitivity. Reduce RF level of generator as needed.
7. Tune to stereo FM station. Adjust R70 for D5 ''0n''.

TYPICAL SPECIFICATIONS

AM SIGNAL-TO-NOISE

RF Level	S/N
12 μV	14 dB
45 μV	27 dB
1000 μV	49 dB

AM RADIO SENSITIVITY

540–1000 kHz	6.7 μV
1000–1600 kHz	8.9 μV

AM RADIO SELECTIVITY

Input level = 2 × Radio AM selectivity level

6 dB audio level Bandwidth 8.0 kHz

Input level = 200 × Radio AM selectivity level

6 dB audio level Bandwidth 24 kHz

AM STRONG SIGNAL DISTORTION

RF Level	% Distortion
80 mV	1
800 mV	1
1500 mV	3

AGC figure of merit = 54.9

AM SPURIOUS RESPONSE

Freq. kHz	dB
700	−15
850	−9.5
913	−12
1051	−8
1074	−11
1198	−16

AM CROSS MODULATION

Ref. Gen. Level = 200 μV (Radio tuned to Ref. Gen.)

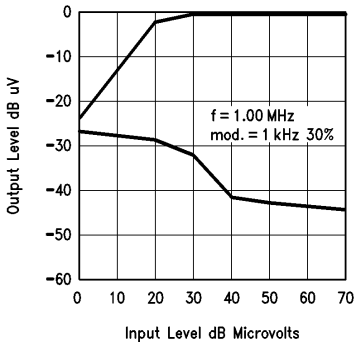
Frequency = 1.01 MHz

Gen #2 Level = 10,000 μV

Gen #2 signal appears 30 dB down*

Frequency = 1.05 MHz

AM Signal to Noise



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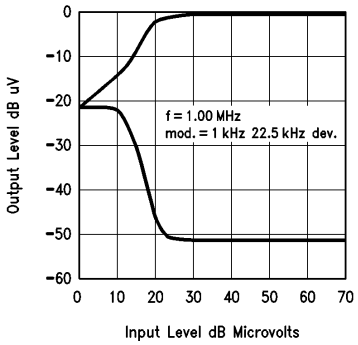
FM Signal to Noise



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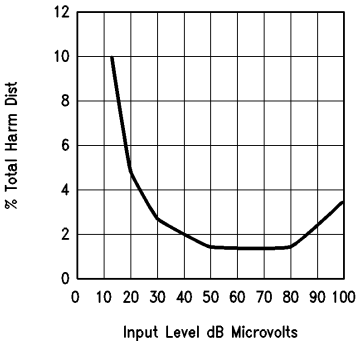
AM Percent Harmonic Distortion



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