MITEL SEMICONDUCTOR

APPLICATION NOTE AN200

Optimising SL6609A Pager Receiver Performance

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This application note describes a setup check list which should be used to ensure that the optimum performance is being obtained from the SL6609A Paging Receiver IC in a given application. Potential practical performance limiting factors are described, with suggestions on how they can be overcome so that they do not limit the SL6609A performance.Mention is also made of how to trade off receiver sensitivity performance with receiver interferer performance (i.e. IP3). Details of an SL6609A receiver board developed by Mitel to work with a standard pager digital board design are included to illustrate the recommendations given.

SL6609A SETUP CHECK LIST

This section is a procedure to follow to ensure that optimum performance is achieved with the SL6609A. It is assumed that the measurements will be carried out under the following conditions:

$V_{CC}1 = 1{\cdot}3V$
$V_{CC}2 = 2{\cdot}7V$
T_{AMB} = room temperature

Other operating conditions will slightly alter the expected measured values specified below.

Note that the local oscillator drive level and receiver gain can be optimised by the user to trade off sensitivity with receiver interferer performance (i.e. IP3), please see Figure 1a and Figure 1b. Sensitivity can be increased to the detriment of receiver interferer performance, by increasing the LNA gain. The receiver gain level specified below is considered by Mitel to achieve a good balance between sensitivity and receiver interferer performance.

Increasing the local oscillator drive level, while reducing the LNA gain (to keep the same overall gain to the receiver test points TPX and TPY), can be used to increase the receiver interferer performance while maintaining a near constant sensitivity level. This is typically true for local oscillator signals in the range 10mVrms to 50mVrms as measured at the receiver local oscillator input pins LOX and LOY.

1. Local Oscillator (LO) Drive Level

(a) Check that the LO frequency is the same as the intended carrier frequency.
(b) The amplitude level at the device pins LOX and LOY should be measured as follows:

The levels can be measured with a high impedance RF FET probe, with an adjustment made for the FET probe loading. It has been assumed here that the RF FET probe will be used with a spectrum analyser that will display the measured voltage in dBm, assuming a 50Ω impedance level. This will not be the actual LO drive level power to the SL6609A as the impedance at the pins LOX and LOY is not 50Ω. For example to measure the level at the pin LOX:

(i) Apply an RF input signal at −73dBm, at a deviation frequency offset from the local oscillator frequency. If the SL6609A audio AGC circuitry is used in the application, it must be disabled by directly connecting pin GTHADJ to pin VR, leaving all existing circuitry connected to pins GTHADJ and VR connected.
(ii) With a scope probe, measure the signal level at the pin TPX, call this level TPX1.
(iii) With a high impedance FET probe measure the level at the pin LOX. Note the new level at pin TPX, call this level TPX2.
(iv) LO drive level (V) =
FET probe measurement (V)×[TPX1 (V)/TPX2(V)] making appropriate conversions for units.

Worked example:

FET probe LOX measurement = −21·9dBm (50Ω system)
TPX1 = 116mVp-p.
TPX2 = 102mVp-p
Actual LOX level = −21.9dBm + 20 log (116/102)
= −20·78dBm (50Ω system)
= 20·44mVrms

The LO drive level correction procedure for FET probe loading, described above, assumes that the SL6609A LO inputs are still being driven in their linear region, i.e. a 1dB increase in LO drive level producing a 1dB increase in receiver gain. This assumption is valid up to LO drive levels of around 25mVrms at the pins LOX and LOY.

For an external LO drive at 150MHz the following are typical measured levels with the passive RC quadrature network (shown in Figure 2):

External LO drive level at pin LOX or LOY (50Ω system)

−15dBm	23·4mVrms+1dB = −19·6dBm+1dB
−18dBm	16·6mVrms+1dB = −22·6dBm+1dB
−20dBm	13·2mVrms+1dB = −24·6dBm+1dB

For an external LO drive at 282MHz the following are typical levels with the passive RC quadrature network (shown in Figure 2):

External LO drive level at pin LOX or LOY (50Ω system)

−15dBm	21·1mVrms+1dB = −20·5dBm+1dB
−18dBm	14·9mVrms+1dB = −23·5dBm+1dB
−20dBm	11·9mVrms+1dB = −25·5dBm+1dB

2. SL6609A Gain

If the audio AGC function of the SL6609A is used in a given application circuit, this must be disabled before undertaking the gain measurement described in this section. To disable the audio AGC action connect pin GTHADJ directly to pin VR, leaving all existing circuitry connected to pins GTHADJ and VR connected.

(a) Match the receiver RF input to 50Ω.
(b) At the receiver RF input, apply a signal at the RF carrier frequency plus a deviation frequency offset, at a level of −73dBm.
(c) Using a 10:1 scope probe measure the levels at pins TPXandTPY. These levels should be 160mVpp+10mV. The difference in levels between the signals at TPX and TPY should be less than 10%, and they should be in quadrature to within an accuracy of 10%. They should also be sinewaves at the same frequency as the RF input deviation frequency.

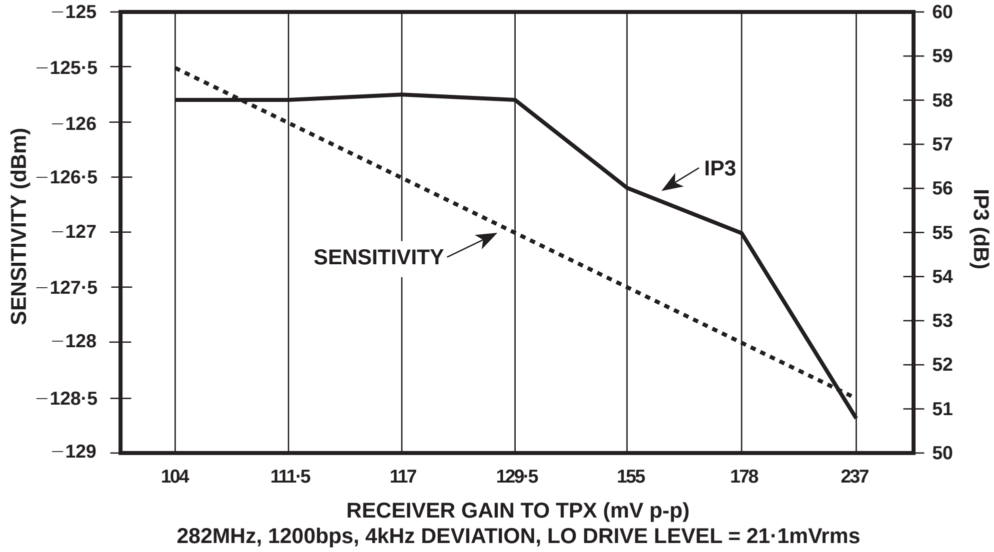

Figure 1a Sensitivity, IP3 v. receiver gain

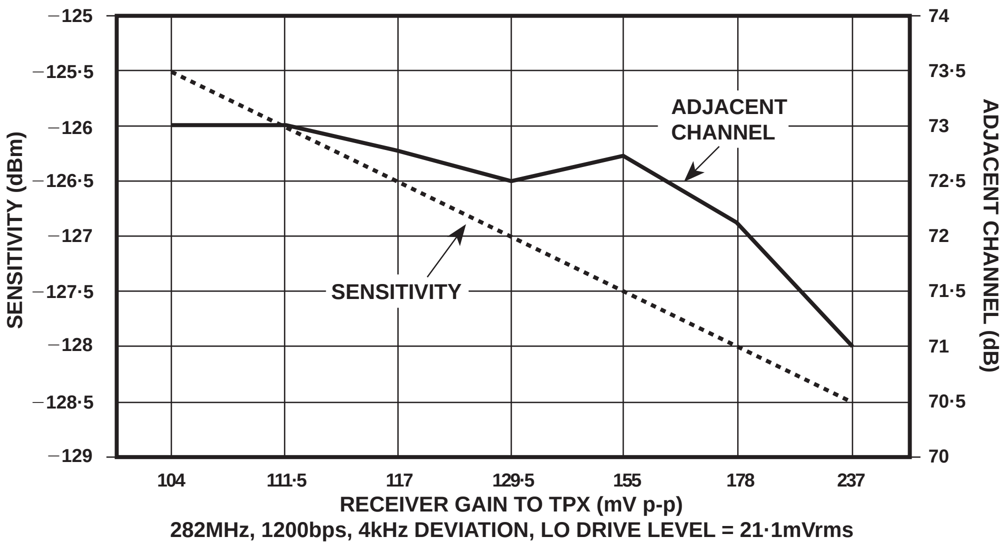

Figure 1b Sensitivity, adjacent channel v. receiver gain

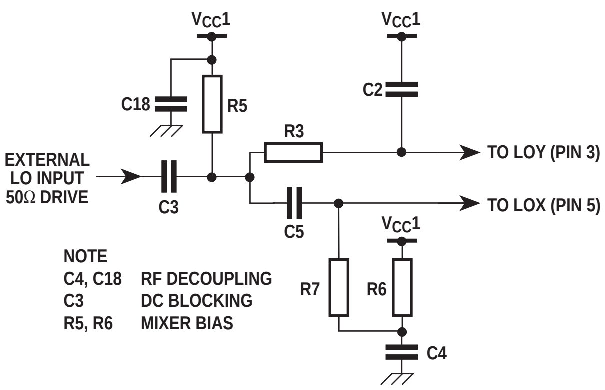

Figure 2 Local oscillator drive network

3. SL6609A Signal To Noise Ratio

Note that if the receiver gain has been set higher or lower than the specified value in Section 2, then the measured values of signal and noise at the pins TPLIMX and TPLIMY wil need to be adjusted accordingly.

(a) Match the receiver RF input to 50Ω.

(b) At the receiver RF input apply a signal at the RF carrier frequency plus the deviation frequency, and at a level of −99dBm.

(c) With a 10:1 scope probe measure the gain at pins TPLIMX and TPLIMY. The amplitude measured should be 60mVp-p +10mV. The difference in levels between the signals at TPLIMX and TPLIMY should be less than 10%, they should be in quadrature, and they should be sinewaves at the same frequency as the RF input deviation frequency offset.

(d) Turn off the RF signal generator connected to the receiver RF input, ensuring that the receiver RF input is still terminated in 50Ω.

(c) With a 10:1 scope probe measure the gain at pins TPLIMX and TPLIMY. The amplitude measured should be 60mVp-p +10mV. The difference in levels between the signals at TPLIMX and TPLIMY should be less than 10%, they should be in quadrature, and they should be sinewaves at the same frequency as the RF input deviation frequency offset.

(d) Turn off the RF signal generator connected to the receiver RF input, ensuring that the receiver RF input is still terminated in 50Ω.

(e) Using a 1:1 scope probe measure the amplitude of the noise at the pins TPLIMX and TPLIMY. If the gain has been set to the level specified in Section 2 the maximum noise level should be 3mVp-p. Note that this must be a measurement of the absolute peaks of the waveforms.
Optimum sensitivity will not be achievable if the noise exceeds the expected value. See the **Possible Noise Problems** Section (below) to try to reduce this noise level to the correct level.

(f) The receiver's RF input should now be connected and matched to an antenna and placed in aTEM cell.
Assuming that the gain of the antenna in the chosen TEM cell is known, it will be possible to calculate the TEM cell RF input level that is equivalent to the −99dBm signal applied in step (b). Apply this level and check that the same level is observed at the test points as in step (c). Note that extreme care has to be taken to ensure that any connections made to the circuitry in the TEM cell have a minimum affect. If the signal level is not correct, it is likely that the antenna is not correctly matched to the receiver RF input, or that the LNA is oscillating (or is close to oscillation) via the antenna.

(g) Ensure that the receiver's RF input is still connected and matched to an antenna. Place the receiver in a TEM cell. Switch the TEM cell RF signal input off, and repeat step (e), measuring the noise at pins TPLIMX and TPLIMY. If the noise level is too high it is likely that the excess noise is being picked up by the antenna. See below to try to reduce this noise level to the correct level.

POSSIBLE NOISE PROBLEMS

Due to the very low RF signal levels that a paging receiver is required to work with, great care has to be taken to minimise noise added to the received signal. The SL6609A has been designed to be a very low noise device, but care has to be taken to ensure that the PCB layout and external circuitry does not become the major noise source. Typical noise degradation mechanisms are:

1. Power supply noise
2. Digital noise pickup
3. Local oscillator re-radiation
4. LNA oscillation

These mechanisms are described in detail below.

Power Supply Noise

The SL6609A is a direct conversion receiver and so the RF signal is down-converted to baseband when still at a low amplitude. Excess noise on the power supply lines can degrade the receiver signal to noise ratio. Noise in the frequency range 500Hz to 25kHz should be minimised. This can be achieved by:

- Careful supply decoupling. RC low pass power supply filters are recommended.
- Careful choice of voltage doubler/regulator to supply $V_{CC}2$. Supply filtering can be most effectively achieved if all frequency components of the voltage doubler lie outside the frequency range 500Hz to 25kHz.
  Two voltage doubler circuits that have been used with the SL6609A are shown in Figure 3. It is good practice to use a two board design if possible, one for the RF circuitry and one for the digital circuitry. It is preferable to place the voltage doubler/regulator circuitry on the digital board.
- Careful PCB grounding. A continuous ground plane for good RF performance is strongly advised. Care should be taken with signal and power supply grounding. Power supply decoupling should be placed as close to the SL6609A as possible. RF decoupling capacitors should be placed as close as possible to the appropriate RF circuit nodes.

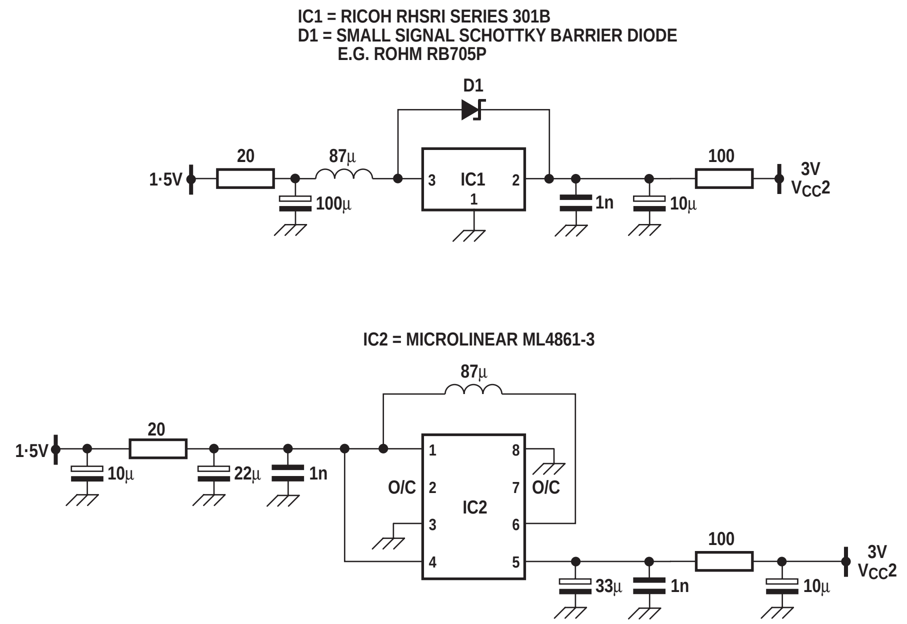

Figure 3 Suggested voltage doubler circuits

- Antenna grounds should be joined at one point to the ground plane. The ground plane should not run underneath the antenna.
- It is important that where possible the appropriate RF de-coupling capacitors within the LNA circuitry that are creating a local RF short (e.g. capacitor pair C17 and VC3) (see Figure 5) are connected to the RF ground plane by a common via hole.

Digital Noise Pickup

Due to the low RF signal levels that the SL6609A is required to receive, noise generated at the RF frequency by harmonics of digital signals can degrade the receiver's performance by coupling in the LNA circuitry directly or via the antenna. Particular care should taken with the SL6609A data output pin (pin 14 DATA O/P). This problem can be minimised by:

- Using a good continuous RF ground plane.
- Careful pcb layout, ensuring that digital signal pins and track routing are kept away from the sensitive receiver RF front end components and the antenna.
- Using low pass filters (e.g. a capacitor) to reduce the level of the higher harmonics on digital tracks.
- The digital decoder and display driver circuits can also generate harmonics that are at the same frequency as the RF frequency. To minimise their affect it is preferable to have these components mounted on a separate board from the antenna, LNA, SL6609A and LO circuitry. It is also good practice to have as much of the digital circuitry inactive during the RF paging message reception period. An example would be to delay writing to the LCD display until after the end of the RF paging message reception.
- Incorporating good RF decoupling on the digital board power supplies and data tracks.

Local Oscillator Re-radiation

As the SL6609A is a direct conversion receiver the local oscillator frequency is the same as the incoming RF frequency. The receiver antenna is therefore tuned to the local oscillator frequency and can easily pick up the local oscillator signal feeding it into the receiver's RF input. This signal will then be mixed in the SL6609A with the local oscillator signal applied directly to the SL6609A local oscillator ports, LOX and LOY. If the local oscillator pickup at the RF receiver input is too large, the sensitivity of the receiver will be degraded. Both the phase and amplitude of the local oscillator picked up at the RF input will affect the level of receiver degradation. With worst case phasing the level of local oscillator signal picked up at the LNA input must be kept below −70dBm (as measured using a high impedance RF FET probe), if the receiver performance is to be unaffected. To minimise local oscillator pickup at the receiver RF inputs the following guidelines should be followed:

- Use a good continuous RF ground plane.
- Position the local oscillator circuitry away from the antenna and the LNA circuitry.
- Keep the local oscillator circuitry on the PCB as compact as possible and minimise the lengths of the tracks connecting the local oscillator output to the receiver local oscillator inputs (LOX and LOY).
- Place a good RF screen over the local oscillator circuitry.
- Ensure that there is no AM modulation on the local oscillator caused by power supply noise. This can be effectively achieved by powering the local oscillator circuitry using the 1V regulator function provided on the SL6609A (pins V_{REG}, REGCNT with an external PNP transistor) and effective RF power supply decoupling. Particular care should be taken that decoupling is made to the appropriate AC ground, e.g. $V_{CC}1$, GND or V_{REF}.

LNA Oscillation

Careful circuit design and layout is required to ensure that this is not a problem. Two main forms of oscillation can occur:

- Oscillation of the LNA near the upper frequency limit of the LNA transistors. This frequency is typically in the region of 1GHz to 5GHz, much higher than the received RF signal frequency. One cause of this is inadequate RF decoupling, or too much circuit gain near the transistor upper frequency limit. The latter can usually be cured by adding a small capacitor to the LNA circuitry to reduce the gain near the upper frequency of the LNA transistor. This type of oscillation can be checked for by observing the SL6609A mixer inputs with a spectrum analyser that is capable of observing the 1 to 5GHz frequency range.
- Oscillation of the LNA at the RF input frequency. This can occur both with the RF receiver input connected to a 500hm input and when an antenna is connected. If oscillation of the LNA, with the RF receiver input connected to a 500hm input is suspected, it can usually be confirmed by checking the input match with a network analyser. If a good 500hm match cannot be achieved it is likely that the LNA is oscillating or very close to oscillating.

If good RF receiver performance and a good RF input match are obtained when the receiver RF input is connected to a 500hm input, but sensitivity with an antenna is slightly below that expected, it is possible that the LNA is oscillating, or very close to oscillating, through a feedback loop via the antenna. This is possible because the antenna and LNA output load circuitry are tuned to the RF input frequency. To minimise the chance of this occurring the LNA output circuitry should be placed as far as is practically possible away from the antenna. Clues that the LNA is oscillating via the antenna are:

- The receiver large signal interferer measurements (i.e. IP3) with an antenna connected are significantly worse (>2dB) than the same measurement carried out with the receiver RF input matched to a 50Ω signal generator.
- The expected gain to the test points TPX and TPY in the TEM cell is significantly different (usually higher) than that expected from the same gain measurement with the receiver RF input matched to a 50Ω signal generator input.

ANTENNA ISSUES

The choice of Antenna size and shape will be largely dependent on the decoder board used and the Pager case size. The GPS RF demonstration board employs a 1mm diameter double loop antenna, the size and shape being determined by the chosen decoder board and case (See Fig.8).

Antenna gain increases with larger enclosed loop area and/or frequency of operation. Hence, using a physically larger antenna for the same frequency or, the same antenna at a higher frequency should result in an improved TEM cell sensitivity. This assumes that the terminal sensitivityvremains constant and that the TEM Cell Sensitivity does not become limited by an antenna noise pick-up problem (e.g. LO reradiation or DATA O/P spikes). If such a noise problem exists then increasing the antenna loop area will make no difference to the TEM Cell Sensitivity, because the Signal/Noise Ratio remains the same (i.e more signal and noise are picked up by the antenna).

Any losses due to Low-Q components in the antenna matching network will result in a direct loss in TEM Cell Sensitivity. Try to use only capacitors in the antenna to LNA matching network.

The antenna gain is also very dependant on the loop resistive loss, and at RF this resistance is dominated by skin effects. It is therefore important that the antenna is made from, or coated with, a low resistivity metal. (e.g. silver).

Antenna gain can be measured with reasonable accuracy by tuning the antenna matching circuit in to 50Ω and measuring the power output with the antenna mounted on the pager board and in the TEM Cell. The antenna gain is the TEM Cell input power minus the antenna output power. For the Mitel dual-loop antenna board, this gain is approximately −39dB in the Elena ETC150F TEM Cell. With this antenna power matched to the LNA (with no losses) a board with a terminal sensitivity of −128dBm should attain a TEM Cell Sensitivity of −89dBm assuming there are no additional noise problems introduced.

AUDIO AGC PROBLEMS

If the loop gain of the Audio AGC circuit is made too great it is liable to break into oscillation at certain input signal levels.

This usually occurs just as the PIN diode turns on, typically about 30dB above the sensitivity level. An oscillation of around 400Hz will be visible at the test points TPLIMX and TPLIMY. The loop gain can be decreased by reducing the value of R8 in Figure 4. Note that R20 in Figure 4 'softens' the turn on of D1.

MITEL RF DEMONSTRATION BOARD

Figure 4 shows the circuit diagram and Figures 5, 6 and 7 show the 3-layer PCB layout. The performance that this board typically achieves when connected to a digital board of a standard pager design, measured in an Elena ETC150F TEM cell system is described below. It should be noted that the Elena ETC150F TEM cell system has a 20dB attenuator connected to the TEM cell input. The TEM cell power inputs quoted below are the values before the 20dB attenuator, so that the level applied to the actual TEM cell is 20dB lower.

Frequency	150MHz
Frequency deviation	4·0kHz
Data Rate	1200bps
Sensitivity	8µV/m (body effect uncorrected)
Sensitivity	4µV/m (6dB body effect correction applied)−89dBm (TEM Cell Drive)
IP3	57dB
Adjacent Channel	73dB
IP2	48dB

The drive level at the local oscillator input pins LOX and LOY was 20mVrms.

A level of 70mVp-p (measured at TPLIMX) was observed for a TEM Cell system input level of −60dBm (corresponds to 220µV/m actual field strength). The antenna used was a double loop, as shown in Figure 8. The peak noise measured at TPLIMX was 3mVpp with the RF carrier switched off.

With the antenna removed and the receiver RF input matched to 50Ω:

- A level of 160mVpp (measured at TPX) was observed for an RF input level of −73dBm, with the RF offset from the local oscillator frequency by 4kHz.
- A level of 60mVpp (measured at TPLIMX) was observed for an RF input level of −99dBm, with the RF offset from the local oscillator frequency by 4kHz.
- The peak noise measured at TPLIMX was 3mVpp with the RF carrier switched off.

Specific points to note on the pcb layout are:

- Careful RF circuitry layout and positioning on the PCB. Special care had to be taken with the ground plane connections of the capacitors directly associated with the antenna circuitry.
- The use of a three layer PCB with the middle layer used exclusively to provide a good continuous RF ground plane.
- The compact LO circuitry layout, short track length of the LO signal lines to the SL6609A LOX and LOY pins and the provision for a full screen over the LO circuitry. The LO circuitry has been powered using the 1V regulator function provided on the SL6609A.
- LNA output load circuitry has been positioned away from the antenna.
- The output track from the SL6609A DATA O/P (pin 14) is positioned well away from the antenna.
- Special attention to RF decoupling.
- Antenna grounds joined to one ground plane point.

The TEM Cell Sensitivity of the GPS RF demonstration board is antenna limited, therefore using a larger loop area antenna should improve sensitivity.

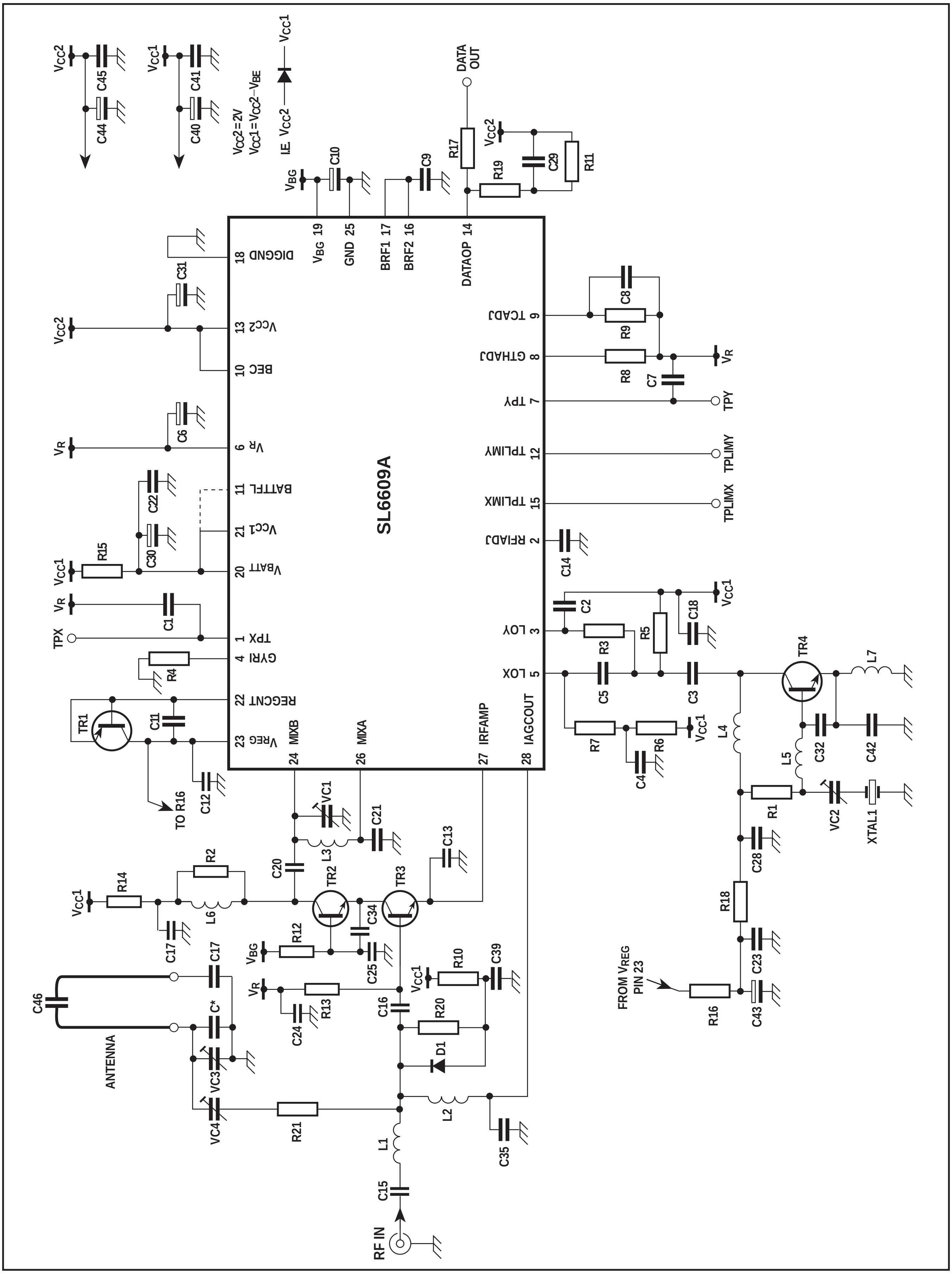

Figure 4 SL6609A application circuit

Resistors		Capacitors		Capacitors (cont.)		Inductors	
R1	1kΩ	C1	1nF	C25	1nF	L1	120nH
R2	820Ω	C2	10pF	C28	10nF	L2	820nH
R3	100Ω	C3	8·2pF	C29	100pF	L3	330nH
R4	100kΩ	C4	1nF	C30	2·2µF	L4	120nH
R5	1kΩ	C5	10pF	C31	2·2µF	L5	27µH
R6	1kΩ	C6	2·2µF	C32	22pF	L6	150nH
R7	100Ω	C7	1nF	C35	1nF	L7	820nH
R8	33kΩ	C8	100nF	C39	1nF	**Transistors**	
R9	220kΩ	C9	1nF	C40	100µF		
R10	Link	C10	2·2µF	C41	33nF	TR1	FMMT399
R11	100kΩ	C11	100nF	C42	13pF	TR2	2SC5065
R12	4·7kΩ	C12	1nF	C43	2·2µF	TR3	2SC5065
R13	4·7kΩ	C13	1nF	C44	100µF	TR4	BFT25A
R14	Link	C14	1nF	C45	33nF	**Crystal**	
R15	Link	C15	1nF	C46	27pF		
R16	Link	C16	1nF	C47	1nF	XTAL1	3rd O/T 49·9MHz (HyQ)
R17	100kΩ	C17	15pF	C*	8·2pF		
R18	680Ω	C18	1nF				
R19	2·2kΩ	C20	1nF	VC1	1-10pF		
R20	47kΩ	C21	2·7pF	VC2	5-20pF		
R21	Link	C22	1nF	VC3	1-10pF		
		C23	10nF	VC4	1-10pF		
		C24	1nF	VC5	5-20pF		

NOTE
Capacitors C19, C26, C27, C33, C34, C36, C37 and C38 are not used in this application

Table 1 Component list for application circuit, Figure 4

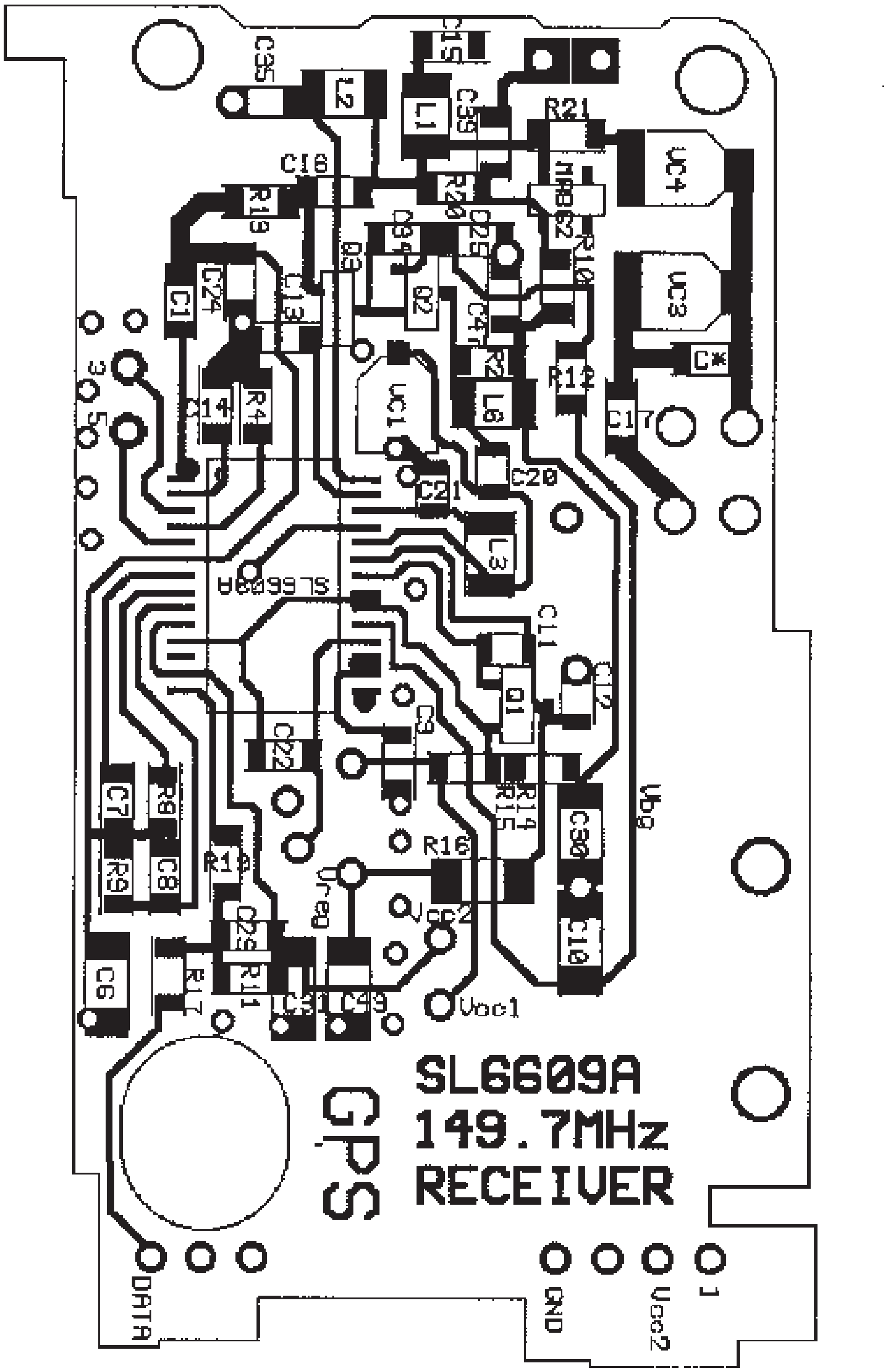

Figure 5 SL6609A application circuit PCB layer 1

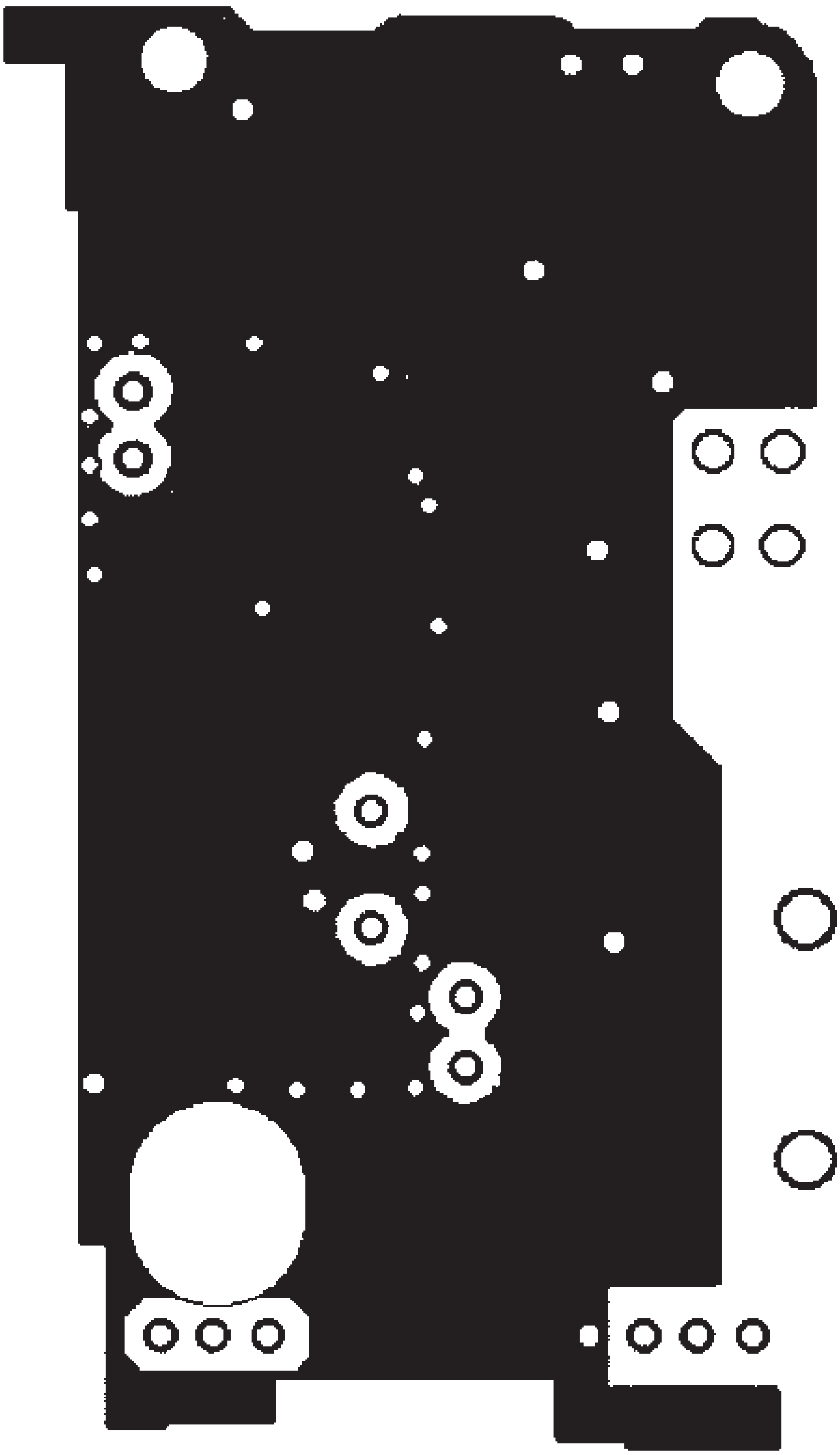

Figure 6 SL6609A application circuit PCB layer 2

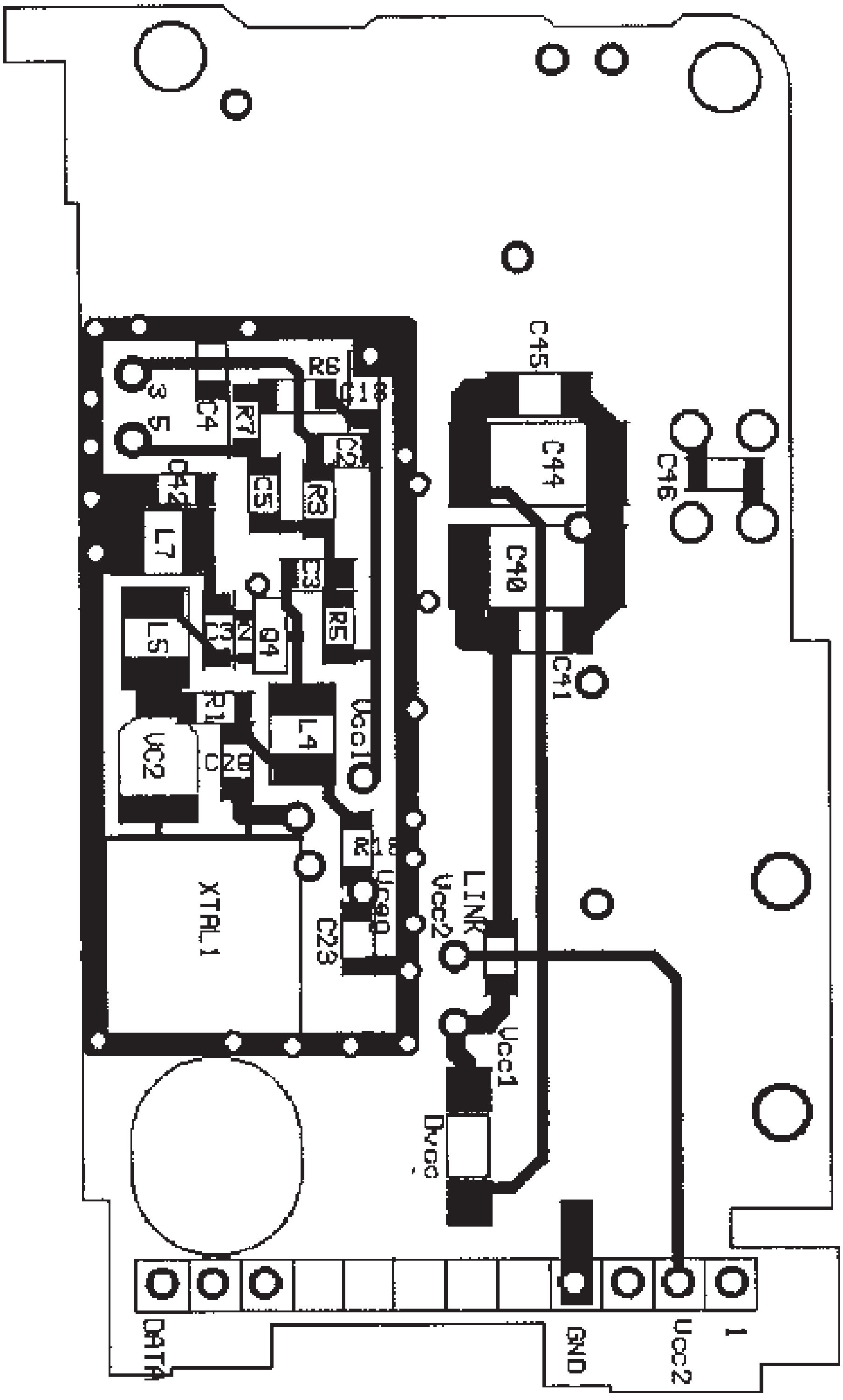

Figure 7 SL6609A application circuit PCB layer 3

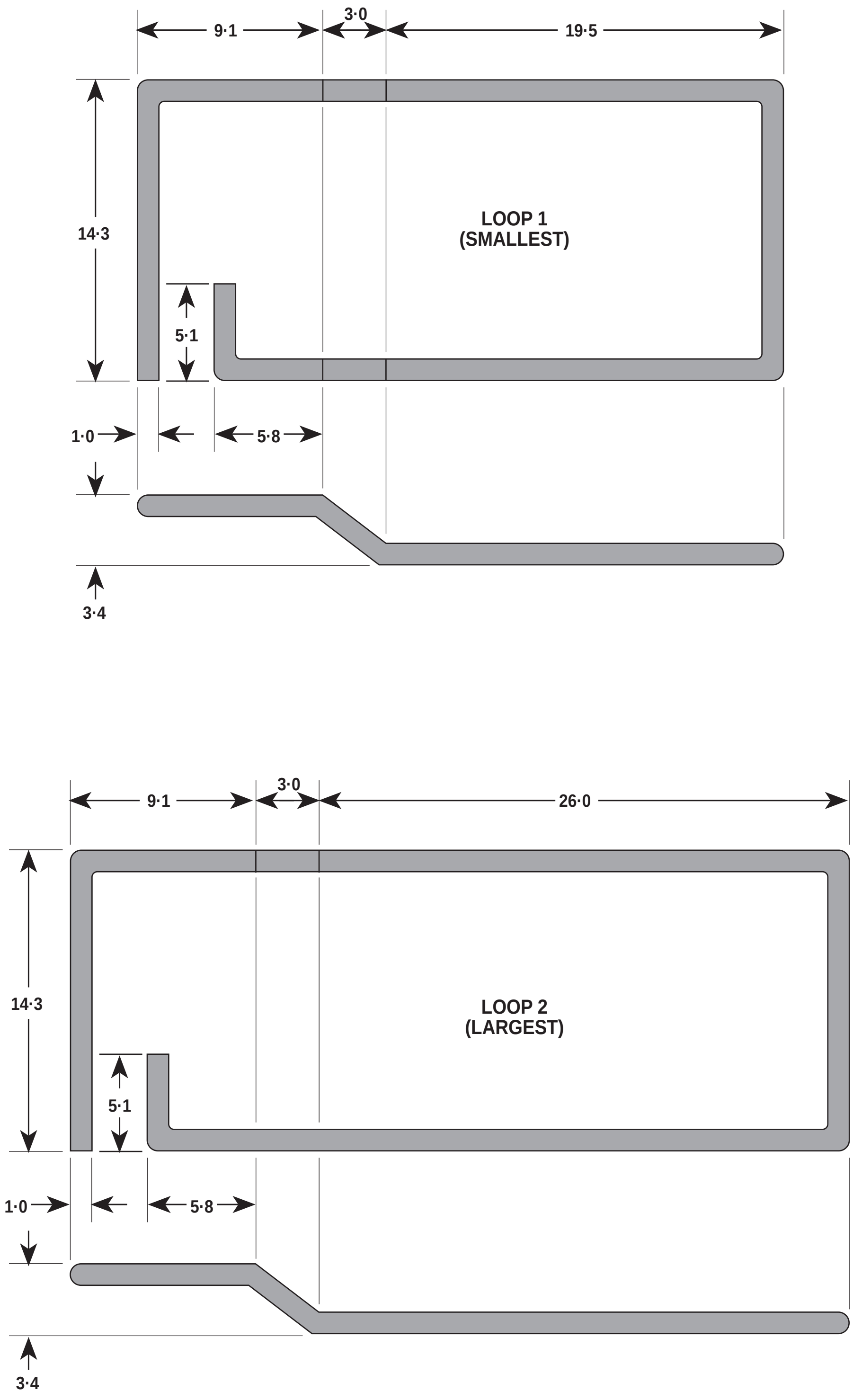

Figure 8 Double wire loop antenna. Dimensions: mm, material: gold plated hard drawn copper.

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