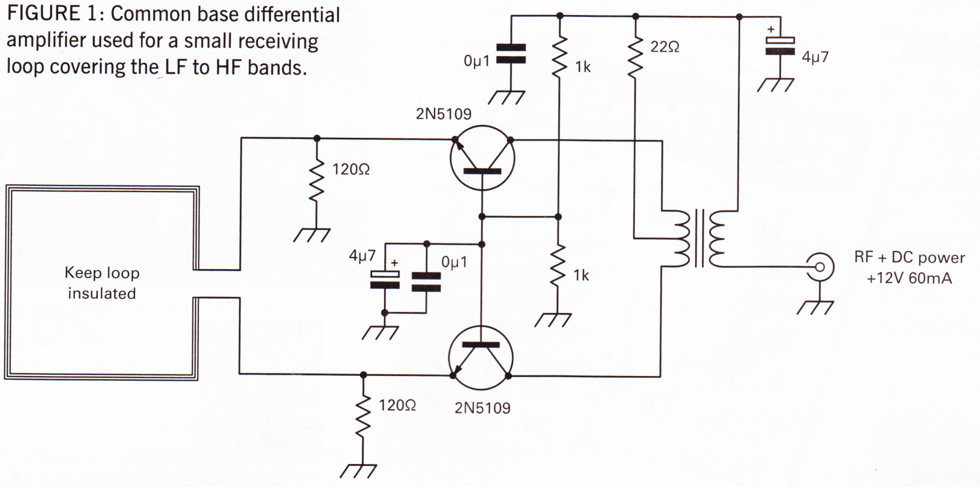
Design Notes

More on small LF antennas plus a mixed bag of feedback

FIGURE 1: Common base differential amplifier used for a small receiving loop covering the LF to HF bands.



BROADBAND ACTIVE LOOPS. We saw last time how an electrically short whip (very much shorter than a wavelength) can show a more-or-less flat frequency response for receiving when followed by a high input impedance broadband amplifier. There is another type of broadband, receiving-only antenna, less well known in amateur circles, but used professionally in the communications intercept and direction finding world. It is the dual of the active whip: the active loop antenna. An electrically small loop – small here means the circumference is less than 10% of the wavelength – looks like a very small loss resistance in series with the fixed inductance of the loop. Compare this with the analogue of the short whip that appears as a very high resistance in parallel with a capacitance.

From basic electromagnetic theory we know the output potential into an open circuit from a single turn small loop of area A in a magnetic field of strength Ho is given by:

$$V = 2\pi \, . \, \mu_o \, . \, A \, . \, Ho \, . \, F$$

(where μo is the permeability of free space, $4\pi * 10^{-7}$)

In free space the magnetic field is directly related to the more commonly referred to electric field strength Eo by the impedance of free space, 120π, or 377Ω. So Eo = Ho * 120π.

Expressing frequency in MHz and using Eo instead of Ho, the equation simplifies to approximately

$$V_{LOOP} = A \, . \, F \, . \, Eo \, / \, 48$$

This exact relationship is often used for measurement of field strength by feeding the output of the untuned loop into a high impedance amplifier. The output of the loop is proportional to frequency, so we most certainly do not have the wanted flat frequency response.

But we know the loop consists of an inductance in series with a small resistance. The inductance has a reactance given by XL = 2π . L and, for now, we'll assume the reactance is significantly larger than the loss resistance. This would usually be the case for loops operating at frequencies above a few tens of kHz. If we could feed the loop into a load, or amplifier, with zero input impedance then we could manage a flat frequency response. From Ohm's law, I = V / XL and, as both the voltage from the loop and XL are proportional to frequency, this cancels. The current delivered into the (zero impedance) load now has a constant relationship with frequency. If there is series resistance present this will add in series with the reactance and the nice cancellation effect will roll off. The result is the loop now has high pass properties with a low end cutoff, where the response is 3dB down, when the reactance equals the total loss resistance. This resistance is made up from the loop's own loss resistance plus the input impedance of the amplifier. This latter term is for most practical purposes the major factor influencing the loop's low frequency performance. More information on small loop antenna can be found at [1].

LOW INPUT IMPEDANCE AMPLIFIER. So, how do we get a near-zero input impedance amplifier? The common base configuration does not appear so often these days, but offers a solution. The ideal, theoretical, input impedance of a bipolar transistor operated in common base is given by 1/(40 . Ie), where Ie is the emitter current. In practice it is a bit more than that due to resistance of the internal connecting leads and the silicon itself, but for RF power devices it is not very much more. So if we were to operate the device at 60mA, the input impedance as a common base stage becomes 1/(40 * 0.06) = 0.4Ω, which is pretty low! A loop has a floating output, so ideally the amplifier should have a balanced input. **Figure 1** shows the circuit diagram of a simple loop amplifier I designed at work many years ago when we wanted to use a small horizontally mounted magnetic loop as an omnidirectional antenna to intercept horizontally polarised skywave HF signals.

One very big advantage of a differential amplifier – and not only in common base – is that decoupling and grounding of the reference electrode becomes less important; it is the connection between the two that is critical and this is nearly always direct. In this design, provided the two bases are strapped together tightly with a direct low impedance connection, any other path to ground does not carry signal current. The input impedance is doubled over the value for one device as both are now in series, but the actual input impedance achieved when running the two 2N5109 transistors at 60mA was of the order of 1Ω – quite close the predicted value.

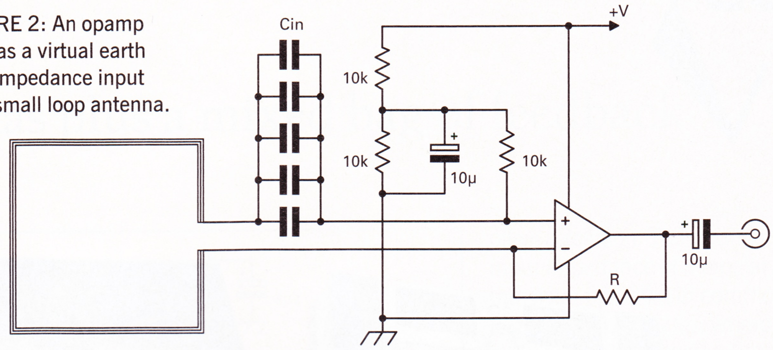
PRACTICAL CONSIDERATIONS. Figure 1 is probably the simplest differential loop amplifier possible. The push-pull transmission line output transformer is not critical. It had a turns ratio of 1+1:1 and was wound using three lengths of trifilar-twisted wire around a ferrite toroid of uncertain heritage (but with enough inductance to allow operation down to a few tens of kHz). Broadband transmission line transformers for low power are remarkably efficient and easy to construct – the ferrite type only affects the lower frequency limit. See the October and November 2010 Design Notes for more on ferrites and transmission line transformers.

To avoid high value DC blocking capacitors in the low impedance input (with their potential series resistance and loss), the loop was connected directly between the emitters of the two transistors. DC biasing required a resistor from the two emitters to ground. So now the loop sits at a positive DC level above ground and had to be insulated. This was not a major issue as the 0.3m diameter loop was small and lightweight, being made from PVC insulated 2.5mm copper wire. The decoupling capacitors on the base do not contribute in any way to circuit operation, but are there to avoid the whole lot floating at RF and prevent potential instabilities. Without them, the whole amplifier is only tied to ground at RF through a few resistors. Since the base-emitter junctions are in parallel at DC, to maintain equal collector current in each device the two transistors should be matched. This is not terribly critical, and choosing two devices from the same batch should ensure sufficient balance in collector currents.

The inductance of that small loop was about 1μH so had 1Ω reactance for a 3dB point at 160kHz. Being one of the first stations to operate on the (then) 73kHz amateur band I had, of course, made sure the output transformer would go down that low and the loop did work quite satisfactorily down there. Overall, it worked quite well enough and allowed collection of the required signals over the whole of the HF band. I do not remember it suffering any overload problems, although with a bigger loop the amplifier may have begun to run into nonlinearity issues and started generating intermodulation products.

Another solution to a zero input impedance is to use an opamp as a virtual earth input. Feedback around the opamp ensures the voltages on positive and negative inputs are made equal, so, by definition the impedance seen looking into these two points must be zero. **Figure 2** shows how an opamp is used this way for a VLF loop. An input capacitor, Cin is needed – and this is quite critical. It must have a high value so reactance is negligible at the lowest frequency of interest and it must also have a low series resistance. For operation at VLF a value of several tens of μF is necessary. It should not be an electrolytic and, ideally, would be made up by paralleling many smaller value low ESR ceramic capacitors. The feedback resistor R works against the loss resistance and reactance of the loop to define the gain; a value of several tens to hundreds of ohms is typical. High frequency opamp technology has now reached a point where they offer

FIGURE 2: An opamp used as a virtual earth zero-impedance input for a small loop antenna.



comparable performance to high power common base amplifiers, but suitable devices are critical and somewhat expensive. For VLF only, standard audio opamps such as the NE5532 will be satisfactory, but are barely suitable for the 137kHz band with very small loops (where plenty of gain is needed). However, several professional loop antennas such as the Wellbrook use this approach.

Chris Trask, N7ZWY has come up with some improved circuit concepts using transformers to linearise the common base amplifier in what he calls 'Augmented Feedback'. A paper describing his technique can be found at **[2]**. [*By coincidence, an article by N7ZWY on design considerations for transformer feedback amplifiers appears elsewhere in this issue – Ed*].

DIRECT SAMPLING SDRS. Direct sampling is where the RF from the receive antenna is digitised after passing through no more than low pass filtering and perhaps a preamplifier, as illustrated in **Figure 3**. It is a technique that is becoming more widespread as the cost of suitable A/D converters plummets and their performance improves, thanks almost wholly to the mobile phone industry. At the moment, off the shelf chips can digitise to 16 bit resolution at sampling rates in excess of 100MHz. This is more than adequate to cover the entire HF spectrum in one go. As a consequence, several such receivers are available to amateurs. The SDR-IQ was probably the first to make a widespread appearance, followed by several others.

All direct sampling SDRs are hindered by one very practical limitation. Sampling to 16 bits at 100MHz generates 1.6G bits of information per second. That is an awful lot of data to deal with; no readily available interface is fast enough to get this reliably to a PC, even if the processor could work fast enough to use it. The solution is to use some on-board fast logic to do some pre-processing that reduces the data rate down to a manageable level that can be sent over a suitable interface. The pre-processing nearly always involves digital downconversion and filtering, so allowing a slower sampling rate. The data can then be sent over USB or Ethernet to a host PC (or whatever). The SDR-IQ uses an off-the-shelf digital downconverter chip and ends up at a maximum of 190kHz bandwidth, set by the capacity of the USB interface. Other, later offerings use logic made in custom gate arrays to format data sent over Ethernet or FireWire, allowing useable bandwidths of several hundreds of kHz.

NEW SDR. The Afedri SDR-Net from Israel is a new low cost entry to the field. With 12 bit sampling at 80MHz it allows 1.25MHz bandwidth to be sent over a LAN or USB 2.0 interface. It is compatible with *Linrad*, *Winrad*, *HDSDR*, *WRPlus*, *SDR console SDR-radio* software and, most importantly, costs around $250. More details can be found at **[3]**.

Also mentioned in *CQ-Ham Radio* is the SDR-49, which looks to be broadly similar. There is a web page, in Japanese, available via a Google translation at **[4]**. Alternatively, a web search for 'SDR-49' will find the original Japanese page.

FEEDBACK. Andrew, G4XZL comments: "After the March 2012 Design Notes article about vector demodulators I remembered that I used the U2794B in a design more than 10 years ago. I used it at 70MHz and it should work at 50MHz too but the trick is that you have to reduce the LO level. On advice from Temic, the original manufacturer,

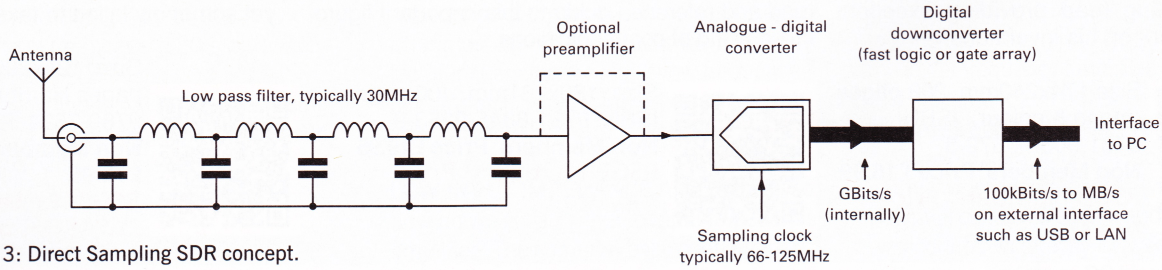


FIGURE 3: Direct Sampling SDR concept.

PHOTO 1: The Tenma 21-10135 SMT pre-heater.

they ecommended -22 to -12dBm for 50MHz and -23 to -12dBm at 70MHz. So unless Atmel have changed the silicon, it should still be applicable. I found one on an old board so might power it up and see if it still works. The big advantage with the Temic parts is the LO is at the RF frequency, which is convenient for use with the cheaper SI-570 or DDS."

Staying with I/Q downconverters, Clive, G7SVI pointed out the LTC5585 IQ demod chip that covers 700 – 3000MHz, or 400 to 4000MHz with reduced performance. Farnell sell this 24 pin QFP chip for around £10. Look on their site **[5]** for the data sheet.

Jon Joyce, GM4JTJ, sent this in:

"...responding to the plea at the end of your July *RadCom* column for ideas. Last year, after having been lent an old book on the history of electricity, it struck me that the humble germanium transistor had been somewhat overlooked due to the relatively fast introduction of the silicon devices. It started me thinking that the lower 'turn-on' voltage of a germanium device might lend itself to some novel applications and so I started thinking about self powered radios.

"Last summer, I started monitoring the potential on my long wire antenna over the course of 24 hour periods using a simple germanium diode doubler circuit and a digital voltmeter. I was staggered to see a maximum of almost 750mV at times. Generally speaking the voltage was at a maximum in the early hours of the morning, falling to tens of mV during the daylight hours. (Trying to wake up at intervals during the night to go out to the shack and take a reading was not the easiest of tasks!) Of course, a self powered radio that only works in the early hours of the morning is not of much use, but I still feel there ought to be some merit in further work into the subject."

And finally... Dave, G8OQW referred me to **Photo 1**, a low cost pre-heater by Tenma for working with surface mount technology. At £36 plus VAT from Farnell [5], this is seriously cheaper than any other similar product and well worth considering. It blows hot air onto the underside of the PCB to raise it to a suitable temperature. While just about capable of reaching the solder melting point for reflowing, it struggles to get there and is really aimed at reworking. This is where the PCB is maintained at a temperature below the solder melting point, with additional heat provided by a soldering iron just where it is needed.

WEBSEARCH

[1] More on magnetic loop antennas – www.vlf.it/looptheo7/looptheo7.htm and www.lz1aq.signacor.com/docs/wsml/wideband-active-sm-loop-antenna.htm

[2] Linearisation of common base amplifiers by 'augmentation' – http://images.rfdesign.com/files/4/1099Trask32.pdf

[3] Afedri SDR-Net SDR – http://4z5lv.net/index.php/afedri-sdr-net-description

[4] SDR-49 - http://tinyurl.com/RC-DN-0912

[5] Farnell – http://uk.farnell.com then search for 21-10135 for the SMT pre-heater or LTC5585 for the 3GHz downconverter IC