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ACTIVE ANTENNA COUPLER FOR VLF

A reprint of a paper published in the "Ham Radio Magazine", Volume 12, Number 10, October 1979, is presented. The circuit designs are applicable to a variety of VLF-HF active antenna receiving systems including Omega and Loran-C for airborne and marine users.

by

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active antenna coupler for VLF

A discussion of active low-frequency and very low frequency antenna preamps, with some details for extending the frequency range to 10 MHz and above

The goal of this project has been to have a single, electrically short antenna operate over a wide frequency range with a minimum of interference or operational problems. The biggest problems are those of local noise pickup from 60-Hz harmonics and overload from strong, out-of-band signals (above 300 kHz). In general, any jfet, mosfet, or even CMOS inverters may be used to provide high power gain, but some circuits work better than others.

The primary purpose of a vlf receiving antenna coupler is to convert the low-level signal at the high-impedance pickup point on a short antenna to a low-impedance level for driving the feed cable back to the receiver. The use of bipolar transistors has invariably resulted in problems due to intermodulation distortion or cross modulation from nearby broadcast-band transmitters. A jfet is far less susceptible to this problem over a wide dynamic range. One of the most common jfets available is the MPF102, which I used in the preamplifier circuit shown in **fig. 1**.

circuit description

The input lightning arrester is of obvious value when a good low-impedance ground system is provided at the antenna mounting. The series input resistors, with the capacitance of the neon bulb and trigger diode, serve as double RC filters to help reduce broadcast-band and high-frequency signals. They also provide static discharge protection. The choice of trigger diode for the low-voltage limiter is critical. Some diacs and thyristors are quite nonlinear and have appreciable resistance/capacitance variations. Some General Electric and Japanese diodes, apparently constructed as back-to-back 14-volt zeners, appear to work best and will prevent burnout of the preamplifier in all but the worst-case, direct-hit situation. You should never use parallel, opposed polarity silicon or germanium diodes in place of a trigger diode, because these produce an almost ideal crystal detector for broadcast-band signals with direct audio signals flowing down the cable!

The output transformer in **fig. 1** is operated in a step-down mode from the jfet drain terminal to provide a higher current driver for the cable at a 150- to 350-ohm impedance level. Fifty-ohm cable is not a perfect match, but at these low frequencies the cable looks like a capacitor and there is no VSWR problem because of the very short electrical length of the cable. The transformer is a standard 600-ohm, center-tapped, line-to-line type. Some UTC subouncer models work just as well and will pass frequencies to 300 kHz or more when terminated with a 330-ohm resistor at the receiver end. Power for the preamplifier flows up the cable from the 330-ohm isolating resistor at the receiver end. The cable capacitance helps limit the high-frequency response. In fact, additional capacitance directly in parallel with the coaxial cable may be used to restrict the preamplifier response for use below 100 kHz.

The coupling capacitor to the receiver should be fairly large if you are interested in signals down to the 10-kHz range or below. The preamplifier will drive 50-ohm cables up to 30.5 meters (100 feet) long and still provide adequate response up to 200 kHz. Seventy-five ohm cable can be used to reduce the cable capacitance for longer runs.

The input impedance and sensitivity of the preamplifier are limited by the input RC protective networks and the relatively high-current operating level. It is a good idea to check the current with a meter temporarily connected in series with the 330-ohm power supply isolating load resistor. Current should be about 4.5 mA at +5 Vdc. If you observe a drastically different current, try changing the 330-ohm load resistor, but be sure to check the preamp operation. In testing dozens of MPF102s, a bad one with too

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low an I_{DSS} specification could be found. You should be able to generate a 50-mV rms output signal, with no distortion at the receiver end, when a 50-mV rms, 100-kHz input signal is connected to the antenna terminal through a 100-pF capacitor. A 100-pF antenna input capacitor will roughly simulate a 2-meter (6-foot) whip antenna for testing purposes with a low-impedance signal source.

Limiting will start at about 100-mV rms, which is more than enough range for most receivers. When the input signal is strong enough to start limiting, the output is reasonably symmetric because of the grounded source and high current operation of the MPF102. The noise figure of about 3 dB is adequate for most uses, since the antenna noise is quite high. Typically, in the 100-kHz region, the atmospheric noise level will be over 10 μV/kHz/meter. With a 3-dB noise figure, the preamp generated noise is about 0.1 μV/kHz.

receiver coupling

The simplest way of coupling the preamp to a receiver is shown in **fig. 1**. Other methods using another transformer to drive two receivers or a tuned input circuit are illustrated in **fig. 2**. The wideband, two-receiver circuit is of value in operating a low-frequency, 10.2-kHz Omega receiver in parallel with a wide tuning range receiver with the same antenna.

The tuned-circuit coupling method has been used for a number of experimental receivers with Polyakov's detector[1] and a direct-conversion method with a balanced mixer.[2] These input circuits might also be used with some of the surplus RAK-RBA receivers, the Palomar Engineers vlf converter, the new Elmek LXK 60-kHz receiver, and with various modern receivers like the Radio Shack DX-300 which tunes down to 10 kHz.

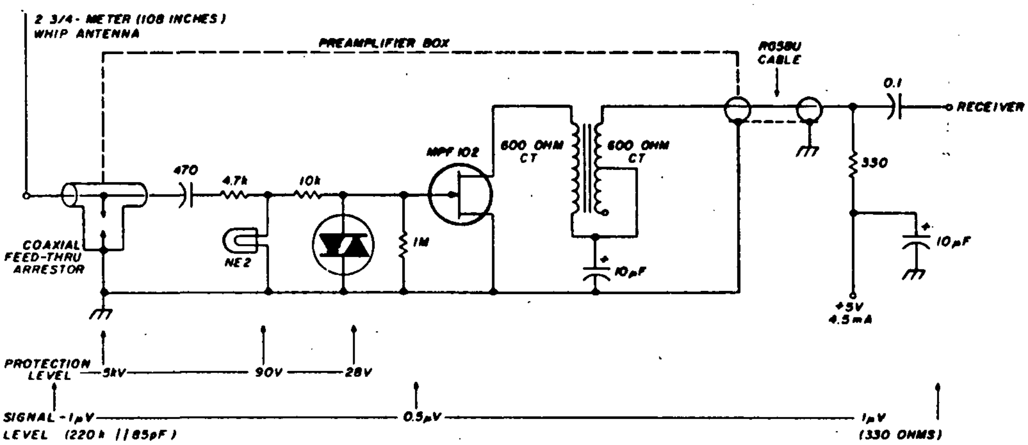


fig. 1. Schematic diagram of one version of a vlf antenna preamplifier. The amplifier's voltage gain is 6 dB, with a noise figure of 3 dB. The −3 dB frequency response, while feeding 15 meters (50 feet) of RG-58U, is 300 Hz to 300 kHz. The maximum signal level without distortion is 100 mV rms. A GE ST-2 or equivalent diode is used as the trigger diode. The coupling transformer is a Mouser TL016.

antenna-mounted preamp

A standard 2-3/4 meter (108-inch) CB whip is used for the antenna, with the preamplifier mounted as shown in **fig. 3**. The antenna should be vertical and in the clear above the immediate terrain if possible. The higher the antenna is mounted, the less will be the ac ground noise pickup problems. The arrangement shown is mounted on a cast iron sewer vent pipe which serves as a good low-impedance ground. A small plastic crutch-tip cap at the end of the antenna whip helps reduce corona discharge problems in turbulent weather. I usually seal all joints, including the preamp box, with silicone rubber sealing compound to prevent moisture from entering. However, in the past, water has sometimes entered the box or antenna connectors. A small bleed hole is drilled in the very lowest or bottom part of the box assembly to drain away any moisture that runs into the assembly.

My only bad experience with lightning was when one of the systems failed due to a strike on a tree nearby. The antenna system apparently suffered a side streamer discharge, but the preamplifier itself was not damaged. The coax cable shield was burned to a crisp inside the jacket with not much obvious damage to the plastic outer jacket. There was a burn point where the cable bent over the roof at a well-grounded rain gutter. The receivers connected in the lab were not damaged.

other antennas

The preamplifier of **fig. 1** can be used with hori-

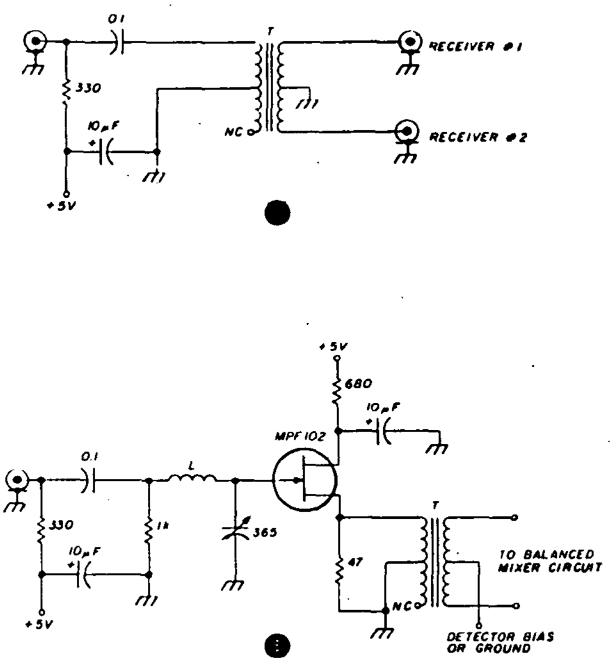


fig. 2. Diagram (A) shows a method for connecting two receivers to a single preamplifier. The transformer is a Mouser TL016. (B) is a tuned input circuit for use with a direct-conversion type of receiver. The inductor is chosen to resonate at the input frequency.

zontal antennas up to 30 meters (100 feet) long, if desired. However, I do not recommend antenna lengths of 150 meters (500 feet), which some DX hunters have used. In many cases, there is not much advantage in long wires over a good vertical radiator. The problem with the long wire is a good ground, underneath the length of the antenna, which will not have fluctuating 60-Hz ground currents. A big problem with long-wire vlf antennas for Amateur users is that the wire picks up 60-Hz harmonics along the entire length of the antenna, which tends to cancel the effectiveness of the length. For a simple installation, a single vertical antenna mounted reasonably in the clear will provide a better signal-to-noise ratio than a long wire strung out over the landscape.

An E-field whip antenna with a wideband preamplifier has one big advantage in that all tuning is done at the receiver end of the circuit. A tuned circuit antenna has to be adjusted for each new frequency range and this becomes a major problem when the antenna is mounted remote from the receiver shack. Loop antennas have a similar restricted bandwidth, compared with this wideband system. H-field loop antennas do have another advantage in that they may be rotated to reduce noise pickup. With an E-field antenna whip, there is no easy way of reducing noise pickup from nearby power lines and varying ground currents except by changing the antenna location, moving it higher, or providing better ground systems directly under the antenna.

audio interference

Audio rectification problems sometimes develop as a result of strong broadcast signals. This does not appear to affect the receiver's signal-to-noise ratio as long as the audio signals do not pass directly into the detector. Some experimental direct conversion receivers have exhibited direct audio feedthrough. This can sometimes be cured with a highpass filter at the receiver input instead of the 0.1-µF coupling capacitor. Tuned transformer or link-coupled input circuits can also be used to reduce direct audio interference feedthrough.

Audio rectification is caused by some nonlinear element or corroded joint and a parallel ground loop where some of the dc current for operating the preamp is being modulated. In one case, on a flat roof building, connecting the antenna mounting to a supposedly conducting member of the roof structure resulted in high broadcast noise pickup at the receiver. The problem was solved by isolating the preamp ground return from the antenna-mount lightning arrester ground such that there is no direct dc connection at the roof. The preamp box "floats" at the end of the coax cable and there is no chance of the roof truss ground providing parallel ground currents along the cable to generate additive or cross modulation effects. This can be done in **fig. 3** by substituting a tight jam-fit plastic pipe coupling for the

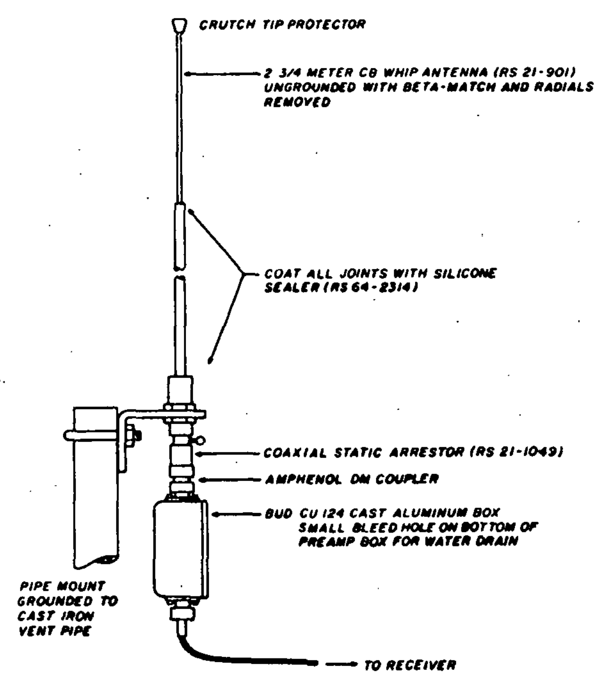


fig. 3. Vlf/low-frequency antenna and preamplifier mounting details.

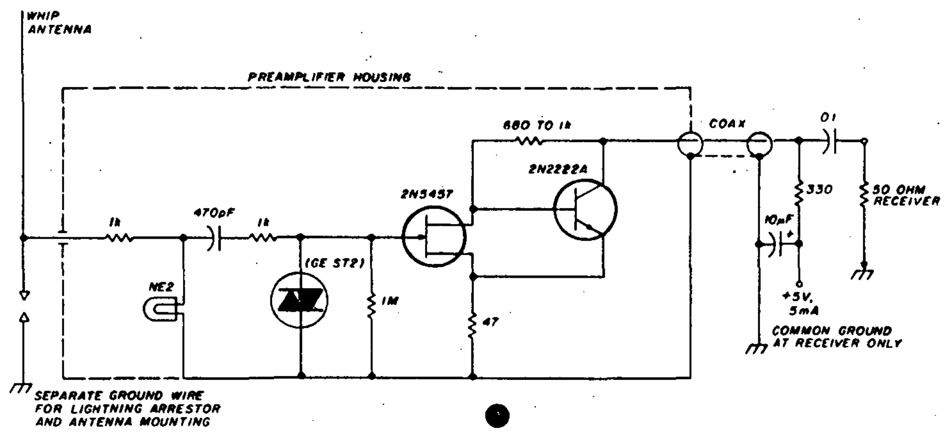
Amphenol DM (double male) fitting with only the center conductors of the uhf fittings connected with a short length of threaded rod. Thus, the antenna mount is insulated from the preamp and cable with the common ground point at the receiver end of the circuit.

wideband modifications

Attempts to operate these jfet preamps over a wider bandwidth results in many problems. One circuit which has been used up to 10 MHz is illustrated in **fig. 4**. The input protection is reduced to provide less attenuation. The trigger diode will typically contribute 12 to 25 pF of added capacity. At vlf, this is not of much consequence, but at 10 MHz this results in about a 5 dB signal loss. **Fig. 4** uses feedback to provide high current gain and unity voltage gain. The gain is adjusted for the I_{DSS} of a particular 2N5457 by changing the value of the 680 ohm to 1-kilohm resistor. I usually try to adjust for unity voltage gain at 100 kHz. This provides the best linearity and a dynamic range of up to 200,000 μV rms. The output impedance of this amplifier is 80 ohms. There will be a VSWR ripple at the higher frequency range when driving a 50-ohm cable as illustrated in **fig. 4B**. VSWR effects at the high end are noted in both cases. The transformer preamp has a still higher output impedance, but this is of little consequence since I was not interested in performance above 200 kHz. Vlf receivers usually look like a 300- to 600-ohm load to the preamp cable with the preamp of **fig. 1**.

With conventional high-frequency receivers, the input may look like a 50-ohm load, which also produces a VSWR effect. The circuit of **fig. 4** has been used for WWV reception at 10 MHz with performance often better than that obtained using an untuned short length of antenna wire. Thus, while there is an apparent 16 dB voltage loss at 10 MHz, the preamp still has some power gain at this frequency when used with a short antenna. Most high-frequency receivers have excess rf gain and a low enough signal-to-noise performance to be used with this preamplifier up to about 10 MHz. The circuit of **fig. 4** is better matched to 75-ohm or 95-ohm cable providing slightly fewer VSWR effects and somewhat better frequency response.

A number of other variations have been tried, including use of two or more transistors in the preamplifier box configured as a source follower driving an emitter follower. None of these have provided



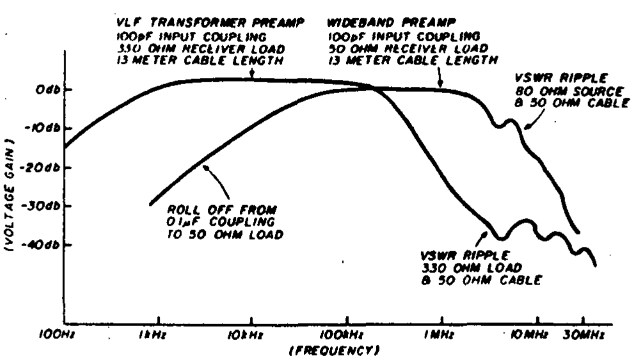


fig. 4. Diagram of a wideband active antenna preamplifier (A). The graph (B) shows the difference between this active preamplifier and that shown in fig. 1.

much better performance than the circuit illustrated in **fig. 4A**. One interesting possibility for those who like to wind their own toroidal transformers would be a bifilar-wound toroid connected as a 4:1 unbalanced step-down transformer from the jfet drain terminal. An inductance of about 1 to 4 mH should provide a wideband device over the range from 60 kHz and up. Surplus pulse transformers have been used in this manner with some success, but it's difficult to obtain a really wideband circuit without reducing all protection at the input to the jfet. There is an inherent problem in that at vlf frequencies you require a very high input impedance for a short whip antenna, but at higher frequencies like 10 MHz, the antenna is a much lower impedance and should be terminated with a lower-impedance circuit.

Still another thought for the experimenter is to consider the methods used in the input circuits of wideband oscilloscopes covering up to 30 MHz. The difficulty here is dynamic range and the circuit complexity, usually requiring a separate dual power supply lead to the preamplifier and perhaps even balanced shielded cable at the output.

High impedance circuits require low capacitance at the input to provide a really high frequency response. One of the most common problems is that of the capacitance to ground of the antenna mount and lightning arrester. This has a big effect on the sensitivity of a short antenna at frequencies like 10 MHz when coupled to a high-Z circuit.

high-gain preamplifier

For very short antenna systems, such as used in mobile or airborne systems, a high-gain preamp is desirable to make up for the low-level signal received on antennas less than 1 meter (3 feet) in effective height. Some vlf receivers are designed such that a low level of 1 μV or so is required for minimum detectable signal. With an electrically short antenna, there may not be enough signal developed to activate the receiver threshold properly, hence, some more gain is often desirable. A preamplifier with 20 dB gain over a frequency range of 100 Hz to 1 MHz is shown in **fig. 5**. This circuit uses the same 2N5457 jfet as in **fig. 4**, but is operated as a voltage amplifier instead of a source follower. The emitter follower provides a low output impedance. This preamp will also work up to about 20 MHz, but the gain drops off to 0 dB or unity at this frequency. The circuit is more susceptible to overload than the previous preamps so some input RC filtering is used to restrict the range.

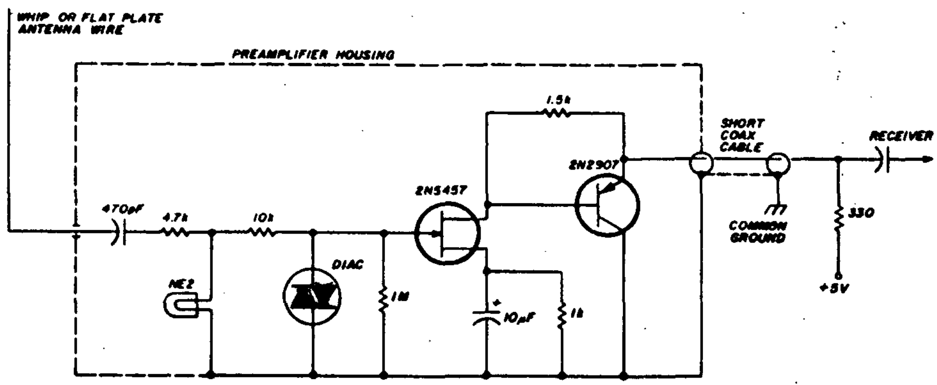


fig. 5. Schematic diagram of a preamp capable of 20 dB gain over the frequency range of 100 Hz to 1 MHz.

Other variations are of course possible, including the use of the output transformer coupling method of **fig. 1** and other biasing schemes for operating the jfet at higher gain. In portable/mobile use, there is not so much concern for a low output impedance cable driver since the receiver can be located close to the preamp with a short length of cable. Circuits like **fig. 5** have been used in general aviation aircraft with good results in the 100-kHz Loran-C range. Marine users are cautioned against using these high-gain preamplifiers because of ground-loop interference problems caused by rusty hulls and poor grounding practice in many boats. A conventional preamplifier more like **fig. 1**, mounted up on a mast well away from the superstructure, will usually provide satisfactory performance, particularly when the coax cable is not grounded to the antenna mount, as discussed previously.

results

This antenna and preamplifier system has been used to receive the 10.2-kHz Omega signals on all eight stations including LaReunion Island, halfway around the world. In Ohio, I regularly receive twelve different Loran-C transmissions from the East Coast, Northeast, and Gulf Coast 100-kHz chains. At night, I observe Loran-C skywave signals from the West Coast chain over 4000 km (2500 miles) away. WWVB puts in a strong 150-μV signal in Ohio, but is often interfered with by MSF in England on the same 60-kHz frequency. Other signals noted are the time frequency standard stations in Switzerland on 75 kHz, Japan on 40 kHz, as well as numerous communications and military FSK-type signals in the 14 to 150 kHz range. The system works well in the 1750-meter Amateur band (160 kHz to 190 kHz), but I have not yet made any serious attempt at DX hunting. The most interesting DX received is on 15.625 kHz, part of the USSR Alpha vlf navigation system.

Harmonics of 60 Hz and TVI from harmonics of the 15.75-kHz horizontal oscillator in nearby TV sets are the most common interference observed in urban locations. In my receiving shack, the 60-Hz troubles usually do not start until the mercury vapor arc lights in front of my home start operating, and other 60-Hz uses increase during the prime evening hours.

In some installations, BCI from nearby transmitters can be a problem. These can usually be cured with an additional low-pass filter or trap inserted in the receiver input circuit, with better grounds on the antenna pole mounting, and with proper care in design of the receiver input circuits to minimize cross modulation problems. Common-mode 60-Hz pickup is sometimes a problem caused by combinations of poor ground connections at the antenna coupler box and the receiver location. If this cannot be cured by relocating the antenna, then another method is to use a balanced, twisted-pair, shielded transmission line. The unused half of the preamp output transformer and a similar balanced input transformer at the receiver with a 330-ohm current limiting resistor connected to the center tap can be used to reduce common mode pickup problems. In general, balanced transmission lines have not been used because it is difficult to obtain suitable lines and weatherproof fittings that will pass frequencies to 300 kHz without excessive expense. It is easier to cure these problems by antenna location or ground changes.

acknowledgments

The effort on vlf/low-frequency antenna couplers has been part of a study of low-cost methods for producing receiving systems for the general aviation community, sponsored by the NASA Langley Research Center. This paper is a direct result of that work. The help of student assistant Edwin Jones is appreciated in testing some of the most recent preamplifier systems.

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