USING THE MAR-X SERIES OF VERY WIDEBAND MONOLITHIC MICROWAVE INTEGRATED CIRCUITS (MMIC)

BUILDING YOUR OWN VLF TO MICROWAVE BROADBAND AMPLIFIER

Very wideband amplifiers have a bandpass (frequency response) of several hundred megahertz, or more, typically ranging from sub-VLF to the low end of the microwave spectrum. An example might be a range of 100 kHz to 1,000 MHz (i.e., 1 GHz), although somewhat narrower ranges are more common. These circuits have a variety of practical uses: receiver preamplifiers, signal generator output amplifiers, buffer amplifiers in RF instrument circuits, cable television line amplifiers, and many others in communications and instrumentation. Unfortunately, as valuable as they are, they were not found in many electronics hobbyist situations until recently[1]. One of the reasons that very wideband amplifiers are rarer than narrower band amplifier circuits is that they are difficult to design and build. A daunting technical task indeed.

By Joseph J. Carr

SEVERAL factors contribute to the difficulty of designing and building very wideband amplifiers. For example, there are too many stray capacitances and inductances in a typical circuit layout, and these form resonances that distort the frequency response characteristic. There are also circuit resistances that combine with the capacitances to effectively form low-pass filters that roll off the frequency response at higher frequencies, sometimes drastically. If the *R-C* phase shift of the circuit resistances and capacitances is 180 degrees at a frequency where the amplifier gain is ≤1 (and in very wideband circuits that is likely), and the amplifier is an inverting type (producing an inherent 180 degree phase shift), then the total end-to-end phase shift is 360 degrees — which is one of the criteria for self-oscillation.

If you have ever tried to build a very wideband amplifier, it was likely to be a very frustrating experience. Until now

Because of new, low-cost devices called silicon monolithic microwave integrated circuits (MMICs), reportedly developed in large part for the benefit of the cable television industry, it is possible to design and build amplifiers that cover the spectrum from near-DC to about 2,000 MHz, and that use seven or fewer components. These devices offer gains of 13 to 30 dB of gain (see Table 1), and produce output power levels up to 40 mW (+16 dBm). Noise figures range from 3.5 to 7 dB. Although several manufacturers offer products, those of Mini-Circuits (P.O. Box 350166, Brooklyn, NY, 11235-0003, USA) are the most easily obtained by electronics hobbyists and amateur radio operators. In this article we will examine the low-cost MAR-x series of MMIC amplifiers.

Drop-in amplifiers

Figure 1a shows the circuit symbol for the MAR-x devices. Note that it is a very simple device. The only connections are RF

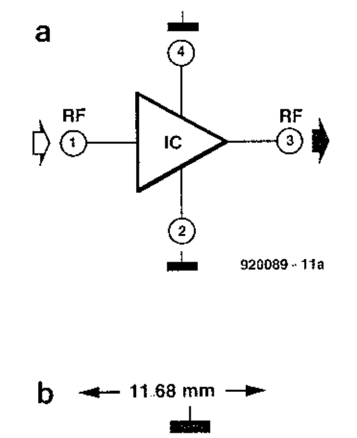


Fig. 1 (a) MAR-x circuit symbol; (b) MAR-x device package; (c) MAR-x internal circuitry.

(1) Note however, that an article called 'MMICs revolutionize wideband RF amplifier design' was published in the January 1988 issue of *Elektor Electronics*. This introductory article was followed by a number of construction projects based on Avantek's MSA series of MMICs (*Tech. Ed.*)

Table 1. Device selection overview

Type number	Colour dot	Gain (500 MHz) [dB]	Max. freq.
MAR-1	brown	17.5	1000 MHz
MAR-2	red	12.8	2000 MHz
MAR-3	orange	12.8	2000 MHz
MAR-4	yellow	8.2	1000 MHz
MAR-6	white	19	2000 MHz
MAR-7	violet	13.1	2000 MHz
MAR-8	blue	28	1000 MHz

input, RF output and two ground connections. The use of dual grounds distributes the grounding, reducing overall inductance and thereby improving the ground connection. Direct current (d.c.) power is applied to the output terminal through an external network. But more of that shortly.

The package for the MAR-x device is shown in Fig. 1b. Although it is an IC, the device looks very much like a small UHF/microwave transistor package. The body is made of plastic, and the leads are wide metal strips (rather than wire) in order to reduce the stray inductance that narrower wire leads would exhibit. These devices are small enough that handling can be difficult; I found that hand forceps ('tweezers') were necessary to position the device on a prototype printed circuit board. A magnifying glass or jeweler's eye loupe are not out of order for those with poor close-in eyesight. A color dot, and a beveled tip on one lead, are the keys that identify pin no. 1 (which is the RF input connection). When viewed from above, pin numbering (1,2,3,4) proceeds counter clockwise from the keyed pin.

Internal Circuitry

The MAR-x series of devices inherently matches 50 ohm input and output impedances without external impedance transformation circuitry, making it an excellent choice for general RF applications. Figure 1c shows the internal circuitry for the MAR-x devices. These devices are silicon bipolar monolithic ICs in a two transistor Darlington amplifier configuration. Because of the Darlington connection, the MAR-x devices act like transistors with very high gain. Because the transistors are biased internal to the MAR-x package, the overall gains are typically 13 to 33 dB, depending on the device selected and operating frequency. No external bias or emitter bias resistors are needed, although a collector load resistor to V_+ is used.

The good match to 50 Ω for both input and output impedances (R) is due to the circuit configuration, and is approximately:

$$R = \sqrt{R_f R_E} \qquad (1)$$

If R_f is about 500 Ω, and R_E is about 5 Ω, the square root of their product is the desired 50 Ω.

Basic circuit

The basic circuit for a wideband amplifier project based on the MAR-x device is shown in Fig. 2. The RF IN and RF OUT terminals are protected by DC blocking capacitors C1 and C2. For VLF and MW applications, use 0.01-µF (10-nF) disk ceramic capacitors, and for HF through the lower VHF (≥ 100 MHz) use 0.001-µF (1-nF) disk ceramic capacitors. But, if the project must work well into the high VHF through low microwave region (>100 MHz to 1000 MHz or so), then opt for 0.001-µF (1-nF) 'chip' capacitors. If there is no requirement for lower frequencies, chip capacitors in the 33 to 100 pF range can be used.

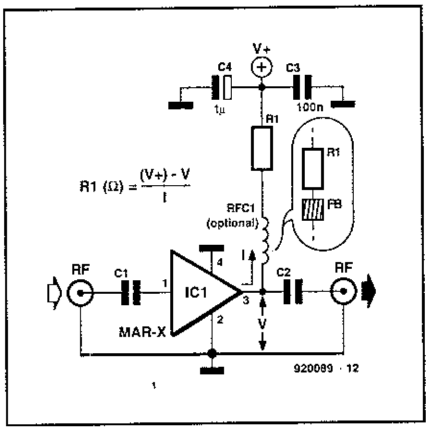


Fig. 2. Generic MAR-x circuit.

The capacitors used for C1 and C2 should be chip capacitors in all but the lower frequency (<100 MHz) circuits. Chip capacitors can be a bit bothersome to use, but their use pays ever greater dividends as operating frequency increases.

Capacitor C3 is used for two purposes. It will prevent signals from A1 from being coupled to the d.c. power supply, and from there to other circuits. It will also prevent higher frequency signals and noise spikes from outside sources from affecting the amplifier circuit. In some cases, a 0.001-µF (1-nF) chip capacitor is used at C3, but for the most part a 0.01-µF (10-nF) disk ceramic will suffice.

The other capacitor at the d.c. power supply is a 1-µF tantalum electrolytic. It serves to decouple low frequency signals, and smooth out short duration fluctuations in the DC supply voltage. Higher values than 1 µF may be required if the amplifier is used in particularly noisy environments.

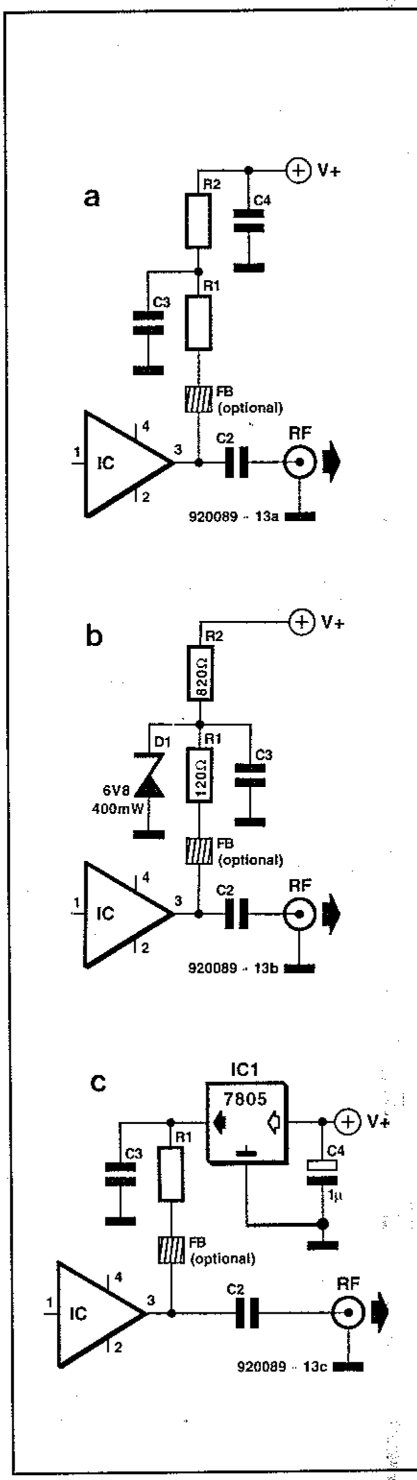


Fig. 3. Power supply schemes: (a) simple resistor circuit; (b) zener-stabilized circuit; (c) three-terminal 5-V voltage regulator stabilized.

Direct current is fed to the amplifier through a current limiting resistor (R1), via the RF OUT terminal on the MAR-x (lead no. 3). The maximum allowable d.c potential is +7.5 V for MAR-8, +5 V for MAR-1 through MAR-4, +4 V for MAR-

7, and +3.5 V for MAR-6 If a minimum voltage V+ power supply is used, e.g. +5 V for MAR-1, make R1 a 47 Ω to 100 ohm resistor. Use only ¼-watt or ½-watt non-inductive resistors, such as the carbon composition or metal film types. The use of higher V_+ potentials (e.g +9 to +12 V) is necessary, use a higher value non-inductive resistor for R1. To determine the value of R1, decide on a current level (I), and do an Ohm's law calculation:

$$R_1 = \frac{(V_+ - V)}{I} \qquad (2)$$

where R is in ohms. In most cases, a good operating current level for the popular MAR-1 is about 15 mA (or 0.015 A)

An example: when a MAR-1 circuit is to be powered from +9-V transistor radio battery, and a device current of 15 mA is required, the theoretical value of R is (9–5)/0.015 = 267 Ω

In practice, a 270-ohm resistor is used.

An optional inductor, RFC1, is shown in the circuit of Fig. 2 This inductor serves two purposes. First, it improves the decoupling isolation of the MAR-x output from the DC power supply by blocking RF signals Second, it acts as a 'peaking coil' to improve gain on the high frequency end of the frequency response curve. It does this latter job by adding its inductive reactance (X_L) to the resistance of R1 to form a load impedance that increases with frequency because $X_L = 2\pi FL$ Depending on application, suitable values of inductance range from less than 0.5 µH to about 100 µH, depending on the application and frequency range. Sometimes, however, the coil forms the total load impedance. In those cases, a decoupling capacitor is used at the junction of RFC1 and R1.

Inductor coils are not without problems in very wideband amplifiers because the stray capacitances between the coil windings form unintended self-resonances with the coil inductance These resonances can distort the frequency response curve and may cause oscillations A popular solution to this problem is to use a small ferrite bead ('FB' in the inset to Fig. 2). The bead acts as a small-value RF choke. These beads have a small hole in them that fits nicely over the radial lead of a ¼-watt resistor.

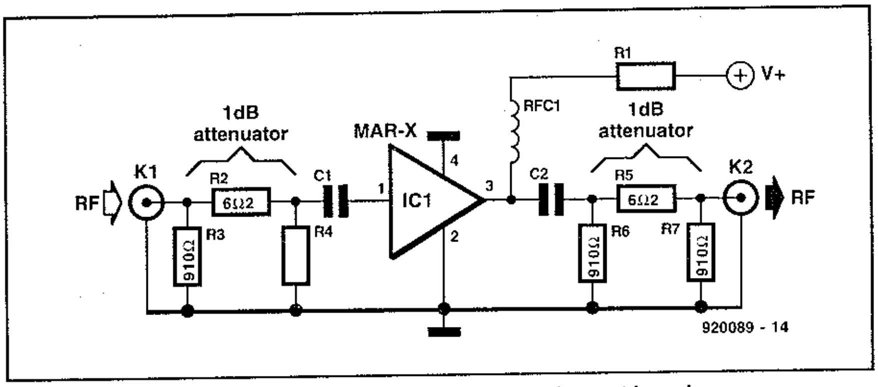


Fig. 4. Use of in-line 1-dB attenuators to stabilize input and output impedances.

Alternative DC power schemes are shown in Fig. 3 The circuit of Fig. 3a splits the load resistance into two components, R1 and R2 The value of R1 will represent most of the required resistance, with R2 typically being 33 to 100 Ω This circuit, like the basic circuit, works well to V_+ voltages of 7 to 9 V, but is not recommended for $V_+ > 9$ V.

Power feed schemes that work well at V+ voltages greater than 9 V are shown in Figs 3b and 3c. Both use voltage regulation to stabilize the supply voltage to the MAR-x device In Fig. 3b, a 6.8-V zener diode holds the voltage applied to R1 constant, and within acceptable range, despite fluctuations in the source V_+ potential

Other MAR-x circuits

The simple circuit of Fig 2 will work well in most cases, especially where the input and output impedance are reasonably stable But if the input source or output load impedances vary, the amplifier may suffer a degradation of performance, or show some instability One solution to the problem is to use resistive attenuator pads in the input and output signal lines Attenuators in an amplifier circuit? Yes that's right. A 1-dB or 2-dB attenuator in the input and output signal lines will pseudo-stabilize the impedances seen by the amplifier, but only marginally affects the overall gain of the circuit In vacuum tube days, we called this type of technique 'swamping'

Figure 4 shows the circuit of Fig 2 revised to reflect the use of simple resistive attenuator pads in the input and output lines. With resistor values of 6.2 Ω for the series element. and 910 Ω for the two shunt lines, the attenuation factor is 1 dB. A 2-dB version uses 12 Ω and 470 Ω, respectively. If 1-dB attenuators are used, the overall gain is the natural gain of the MAR-x device less 2 dB (or 4 dB if 2-dB attenuator pads are used) The resistors used for these attenuator pads must be non-inductive types, such as carbon composition or metal film types. If the amplifier is to be used at the higher end of its range, chip resistors are preferable to ordinary axial lead resistors.

An alternative approach is to use manufactured shielded RF 50-Ω attenuator pads. Another of Mini-Circuits products are the AT-1 and MAT-1 1-dB attenuators; they are suitable for the purpose, and match the frequency range of most of the MAR-x products These low-cost devices are similar except for size, and are intended for mounting on printed circuit boards.

Keep in mind that the use of attenuators is not for free (TANSTAFL principle: *There Ain't No Such Thing As a Free Lunch*). The resistive attenuators reduce the gain (as mentioned before), but also increase the noise factor by an amount set by the loss factor of the attenuator pad.

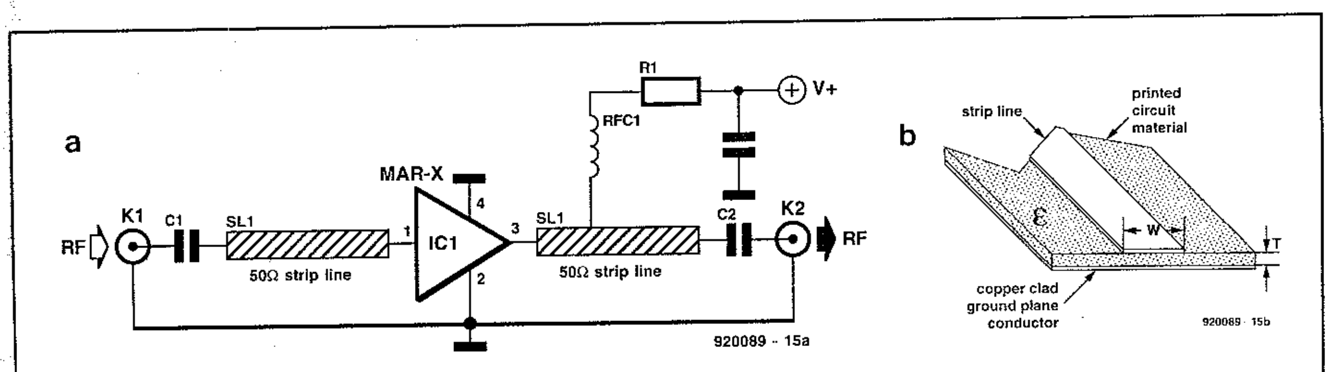


Fig. 5. (a) MAR-x amplifier with strip line input and output circuits; (b) strip line detail.

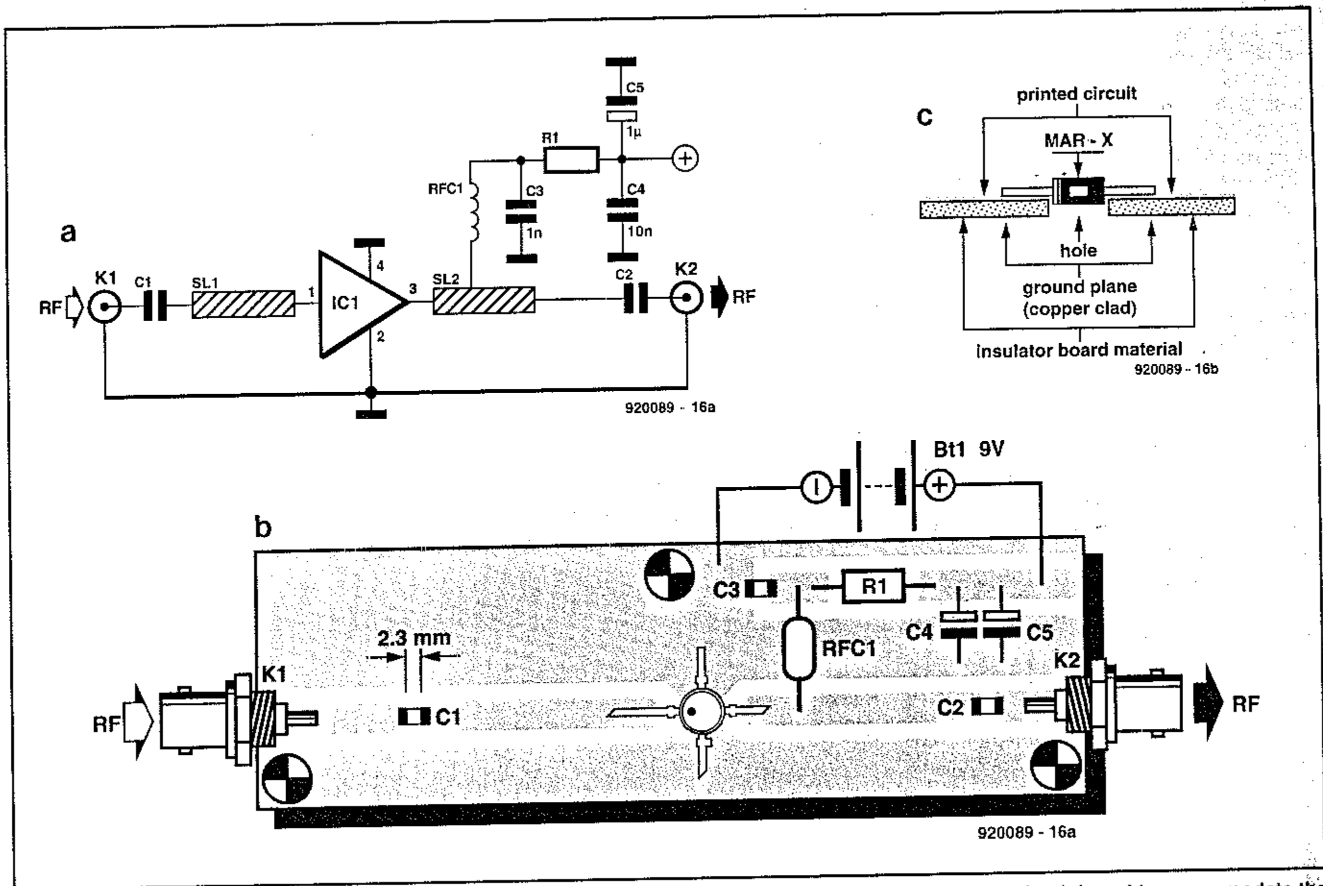


Fig. 6. (a) Typical circuit diagram and (b) PCB layout for a MAR-x amplifier; (c) a hole is cut into the printed circuit board to accommodate the MAR-x body

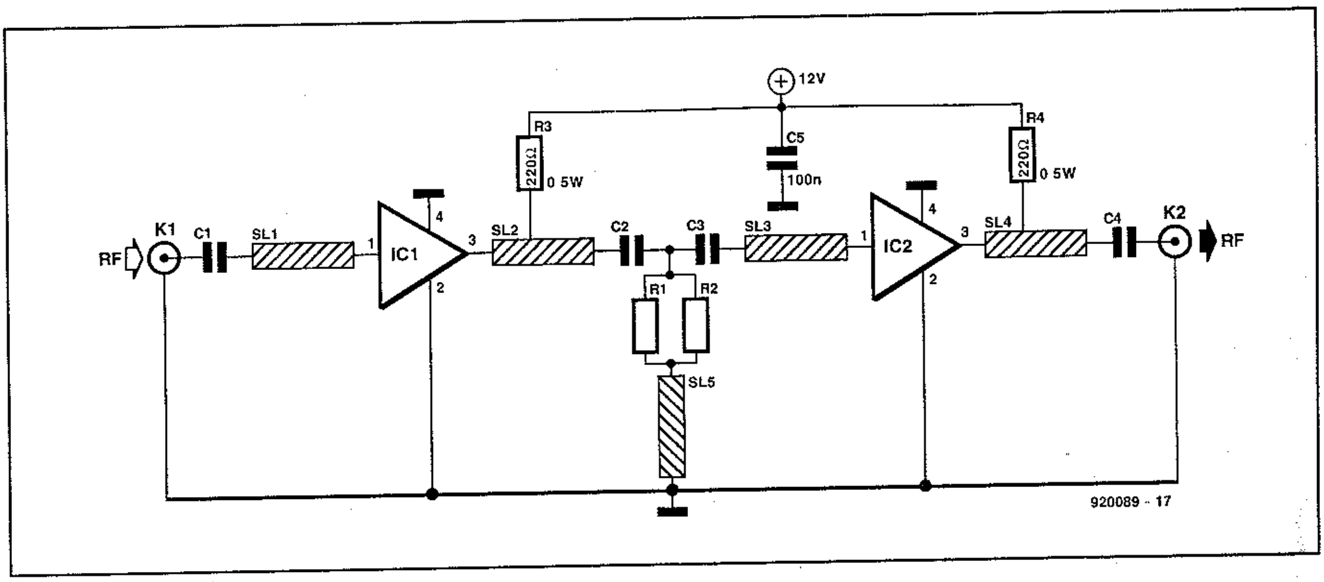


Fig. 7. Cascade MAR-8 amplifier.

For VHF, UHF and low-end microwave amplifiers it may be preferable to use a printed circuit strip line transmission line for the input and output circuits. Figure 5a shows such a circuit with input (SL1) and output (SL2) strip lines, while Fig. 5b shows detail of how these lines are made. The characteristic impedance (Z_o) of the line is a function of the relative dielectric constant of the printed circuit material (ε_r), the thickness of the material (*T* in Fig. 5b), and the width (*W* in Fig. 5b) of the strip line conductor. Common epoxy G-10 printed circuit boards ($\varepsilon_r \approx 4.8$) are usable to 1000 MHz and work well to about 300 MHz. Above 300 MHz the losses increase significantly. PTFE woven glass fiber printed circuit board ($\varepsilon_r \approx 2.55$) operate to well over 2,000 MHz, which is higher than the upper limit of the MAR-x devices. Widths required for 50 Ω strip lines for various printed circuit board materials are shown in Table 2.

Figure 6b shows the circuit layout of a typical printed circuit board for a MAR-x wideband amplifier. The circuit for the layout is shown in Fig. 6a. The printed circuit board should be double clad, i.e., clad with copper on both top and bottom. The strip lines at the input and output are etched from the component side of the printed circuit material, not the bottom side as is common practice in lower frequency projects. The reason for this approach is to reduce the inductance of the leads to the MAR-x device.

Strip lines should not contain abrupt discontinuities, or else parasitic losses will increase. It is common practice to taper the line over a short distance from the strip line to the width of the MAR-x leads right at the body of the device.

Another tactic to keep stray lead inductances to a minimum is to drill a small hole in the printed circuit to hold the body of the MAR-x (Fig. 6b). The diameter of the MAR-x package is 0.085 inch (approx. 2.15 mm), and the hole should be only slightly larger.

The capacitors in the input and output circuit, as well as the decoupling capacitor at the junction of RFC1 and R1, are chip capacitors. The break in the strip line to accommodate these capacitors should be just wide enough to separate the ohmic contacts at either end of the capacitor body. For the 1-nF (0.001 μF) chip capacitors that I used in making a model in preparation for this article, the insulated center section between contacts on the capacitors averaged 0.09 inch (2.3 mm) as measured on a vernier caliper set.

It is essential to keep ground returns as short as possible, especially when the amplifier operates at the higher end of its range. If you opt to use the ground plane cladding for the d.c. and signal return, plated through holes are required between the two sides of the board. These plated through holes must be placed directly below the ground leads of the MAR-x package.

Table 2. Values for 50-Ω strip line (see Fig. 5b)

Material	ε_r	*T*	*W*
G-10 epoxy fiberglass	4.8	0.062 in. 1.58 mm	0.108 in. 2.74 mm
PTFE woven glass fiber	2.55	0.010 in. 0.254 mm	0.025 in. 0.635 mm

Table 3. Cascade amplifier design details (see Fig. 7)

Component	Case-A	Case-B
R1	124 Ω	69.1 Ω
R2	69.8 Ω	69.1 Ω
C1, C4	470 pF	68 pF
C2	1.5 pF	2 pF
C3	7.5 pF	2 pF

Capacitors are chip type. Resistors are 1% chip type.

	W × L	W × L
SL1	0.1 × 0.1 in. 2.54 × 2.54 mm	0.04 × 0.1 in. 1.02 × 2.54 mm
SL2	0.1 × 0.05 in. 2.54 mm × 1.27 mm	0.04 × 0.1 in. 1.02 × 2.54 mm
SL3	0.1 × 0.2 in. 2.54 × 5.08 mm	0.04 × 0.1 in. 1.02 × 2.54 mm
SL4	0.1 × 0.1 in. 2.54 × 2.54 mm	0.04 × 0.1 in. 1.02 × 2.54 mm
SL5	0.05 × 0.2 in. 1.27 × 5.08 mm	0.05 × 0.2 in. 1.27 × 5.08 mm

Multiple device circuits

The MAR-x devices can be connected in cascade, parallel or push-pull. The cascade connection increases the overall gain of the amplifier, while the parallel and push-pull configurations increase the output power available.

The simplest cascade scheme is to connect two stages such as Fig. 2 in series so that the output capacitor of the first stage becomes the input capacitor of the second stage. Figure 7 shows a somewhat better approach. This circuit uses strip line matching sections at the inputs and outputs, and between stages. Table 3 gives the dimensions of these lines for two different cases: Case-A is for a 100 to 500 MHz amplifier, and Case-B is for a 500 to 2,000 MHz amplifier. In both cases the MAR-8 device is used.

The parallel case is shown in Fig. 8. MAR-x devices can be connected directly in parallel to increase the output power capacity of the amplifier. In the case of Fig. 8, there are four MAR-x devices connected in parallel. Other combinations are also possible. I built a two-up version for a signal generator output stage recently. The output power in Fig. 8 will be four

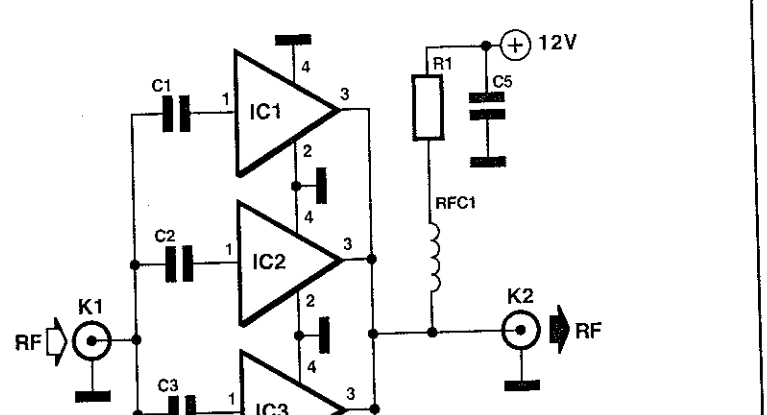


Fig. 8. Parallel combination increases output power fourfold for same gain, but cuts input and output impedances by four.

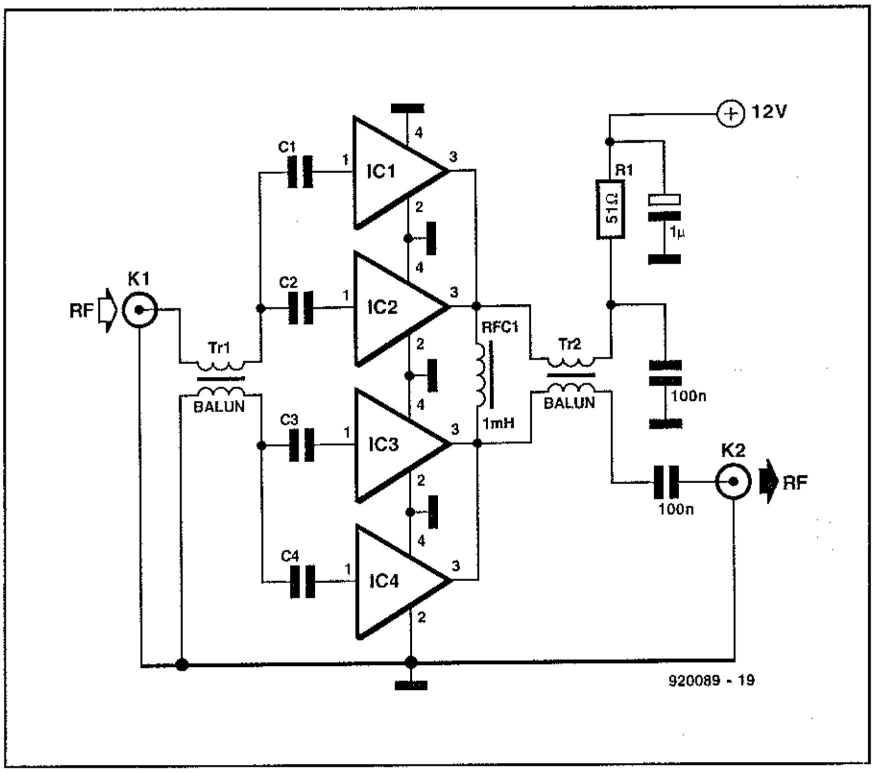


Fig. 9. Parallel push-pull amplifier.

times the power available from a single device.

Unfortunately, in the parallel amplifier the input and output impedances are no longer 50 Ω, but rather it is $50/n$ where n is the number of devices connected in parallel. In the case shown in Fig. 8, there are four devices to the input and output impedances are 50/4 or 12.5 Ω. An impedance matching device must be used to transform the lowered impedances to the 50 Ω standard for RF systems. Because most impedance transformation devices do not have the same wide bandwidth as the MAR-x devices, there is an obvious degradation of the bandwidth of the overall circuit.

The push-pull configuration is shown in Fig. 9. In this circuit there are two banks of two MAR-x devices each. The two banks are connected in push-pull, so this circuit is correctly called a push-pull parallel amplifier. This circuit retains gain and the increase in power level of the parallel connection, but improves the second harmonic distortion that some parallel configurations exhibit. Push-pull amplifiers inherently reduce even-order harmonic distortion.

The input and output transformers (T1 and T2) for the circuit of Fig. 9 are balun (BALanced UNbalanced) types, and are used to provide a 180-degree phase shift of the signals for the two halves of the amplifier. The balun transformers are typically wound on ferrite toroidal coil forms with #26 AWG or finer wire. Because the balun transformers are limited in frequency response, this circuit is typically used in medium wave and shortwave applications. A common specification for these transformers is to wind 6 or 7 bifilar turns on a toroidal form, the turns made of #28 AWG enameled wire wrapped together to form a twisted pair of about five twists to the inch (≈ 2 twists per cm). Suitable cores (and a catalog) are available from Amidon Associates (P.O. Box 956, Torrance, CA 90508, USA).

Conclusion

The MAR-x devices are an extremely easy way to build RF amplifiers from frequencies near d.c. to the low microwave region. They are easy to use, and well behaved. Hobbyists will find them very convenient for a wide variety of applications. ■

CORRECTIONS

4-Megabyte printer buffer

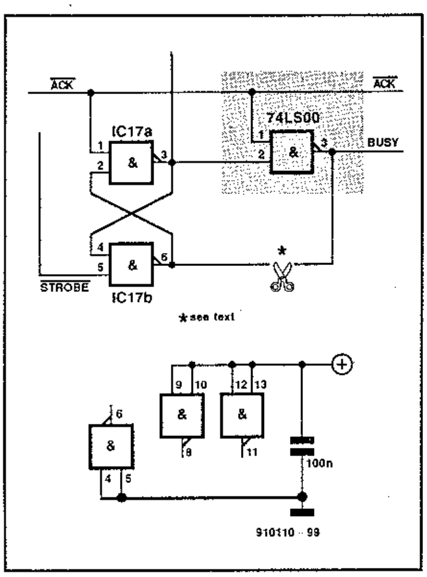
June 1992

Two points regarding this project.

(1) The input of the buffer is designed to be Centronics compatible. Problems may occur when this standard is not respected by the computer or the software. A number of 'fast' PCs (in particular 386 and 486 based machines) appear to have printer interfaces derived from the Epson standard. These interfaces in general do not wait for the ACKNOWLEDGE signal, but instead process the BUSY signal.

Handshaking problems that may occur between these PCs and the printer buffer may be solved by combining the BUSY and ACKNOWLEDGE signals as shown in the diagram opposite. The result of the modification is that the printer buffer behaves like an Epson-compatible peripheral device.

(2) An updated version of the control software (in EPROM) is available that enables 1-Megabyte (1M × 8 and 1M × 9) SIP/SIM modules with three ICs to be used in the printer buffer.



Inductance-capacitance meter

March 1992

Terminals 'A' and 'B' should be transposed in the circuit diagram of the meter circuit proper (Fig. 4 on page 32).

Milli-ohm measurement adaptor

April 1992

To prevent its contacts burning out, switch S_1 must not be operated when an inductive component is connected to the adaptor.

Contrary to what is said under the heading 'Extensions', the reference inputs of the DVM are connected to the pole of S_{1b} and ground, while the 'normal' DVM inputs are connected to the resistor to be measured.