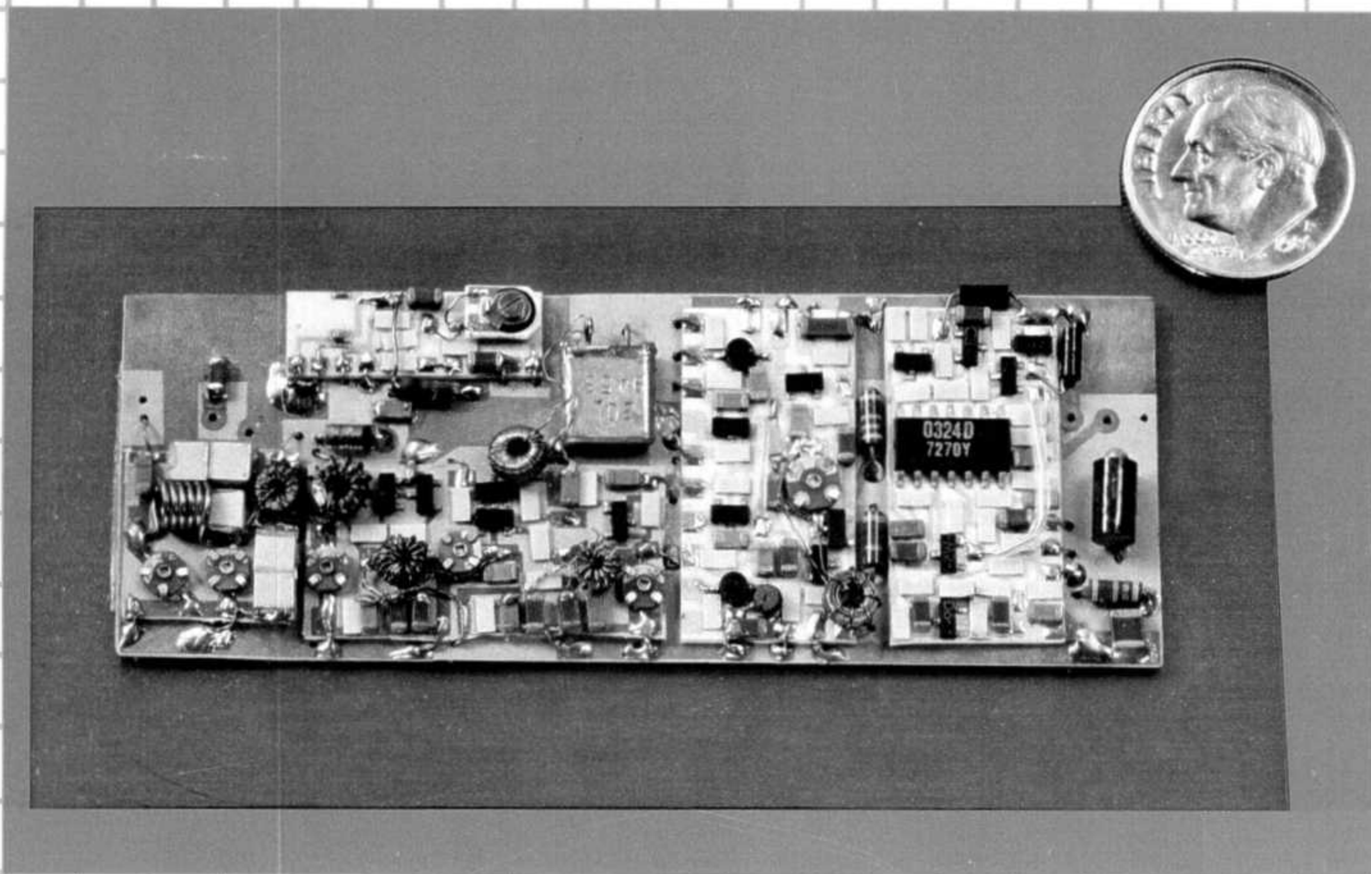
QEX 53

$1.75

JULY 1986

The ARRL Experimenter's Exchange



QEX (ISSN: 0886-8093) is published monthly by the American Radio Relay League, Newington, CT USA.

David Sumner, K1ZZ
Publisher

Paul L. Rinaldo, W4RI
Editor

Maureen Thompson, KA1DYZ
Assistant Editor

William Conwell, K2PO
Geoffrey H. Krauss, WA2GFP
Bill Olson, W3HQT
Contributing Editors

Lisa Fuini
QEX Circulation

Michelle Chrisjohn, WB1ENT
Production Supervisor

Deborah Sandler
Typesetting and Layout

Sue Fagan
Graphic Design Supervisor

David Pingree
Technical Illustrator

Lee Aurick, W1SE
Advertising Manager

Sandy Gerli, AC1Y
Deputy Advertising Manager

Technical Department
Charles L. Hutchinson, K8CH
Manager
Gerald L. Hall, K1TD
Deputy Manager
Paul Pagel, N1FB, Mark Wilson, AA2Z
Senior Assistant Technical Editors
Bruce O. Williams, WA6IVC
Assistant Technical Editor

Production Department
E. Laird Campbell, W1CUT, *Manager*
Joel P. Kleinman, N1BKE, *Deputy Manager*

Circulation Department
Lorry Evans, KA1KQY, *Manager*
Debra Chapor, *Deputy Manager*

Offices

225 Main St, Newington, CT 06111 USA
Telephone: 203-666-1541
Telex: 650215-5052 MCI
Electronic Mail: MCI MAIL ID:215-5052
(user name ARRL)

Subscription rate for 12 issues:
In the US by Third Class Mail:
ARRL Member $6, nonmember $12;
US by First Class Mail:
ARRL Member $11, nonmember $17;
Elsewhere by Airmail:
ARRL Member $21, nonmember $27.

QEX subscription orders, changes of address, and reports of missing or damaged copies may be marked: *QEX* Circulation.

Members are asked to include their membership control number or a label from their *QST* wrapper when applying.

TABLE OF CONTENTS

COLUMNS

ABOUT THE COVER

This complete commercial transmitter was fabricated using surface mount technology (SMT). Technological forecasters claim that by the mid-1990s, this method of adhering components to a circuit board will be widely used by US manufacturers. More information on surface mount manufacturing processes can be found on p 4.

THE AMERICAN RADIO RELAY LEAGUE, INC

The American Radio Relay League, Inc, is a noncommercial association of radio amateurs, organized for the promotion of interest in Amateur Radio communication and experimentation, tor the establishment of networks to provide communications in the event of disasters or other emergencies, for the advancement of the radio art and of the public welfare, for the representation of the radio amateur in legislative matters, and for the maintenance of fraternalism and a high standard of conduct.

ARRL is an incorporated association without capital stock chartered under the laws of the State of Connecticut, and is an exempt organization under Section 501(c)(3) of the Internal Revenue Code of 1954. Its affairs are governed by a Board of Directors, whose voting members are elected every two years by the general membership. The officers are elected or appointed by the Directors. The League is noncommercial, and no one who could gain financially from the shaping of its affairs is eligible for membership on its Board.

"Of, by, and for the radio amateur," ARRL numbers within its ranks the vast majority of active amateurs in the nation and has a proud history of achievement as the standard-bearer in amateur affairs.

A bona fide interest in Amateur Radio is the only essential qualification of membership; an Amateur Radio license is not a prerequisite, although full voting membership is granted only to licensed amateurs in the US and Canada.

Purposes of *QEX*:

1) provide a medium for the exchange of ideas and information between Amateur Radio experimenters

2) document advanced technical work in the Amateur Radio Field

3) support efforts to advance the state of the Amateur Radio art.

All correspondence concerning *QEX* should be addressed to the American Radio Relay League, 225 Main Street, Newington, CT USA 06111. Envelopes containing manuscripts and correspondence for publication in *QEX* should be marked: Editor, *QEX*.

Both theoretical and practical technical articles are welcomed. Manuscripts should be typed and double spaced. Please use the standard ARRL abbreviations found in the 1985 and 1986 ARRL Handbooks and in the January 1984 issue of *QST*. Photos should be glossy, black-and-white positive prints of good definition and contrast, and should be the same size or larger than the size that is to appear in *QEX*.

Any opinions expressed in *QEX* are those of the authors, not necessarily those of the editor or the League. While we attempt to ensure that all articles are technically valid, authors are expected to defend their own material. Products mentioned in the text are included for your information; no endorsement is implied. The information is believed to be correct, but readers are cautioned to verify availability of the product before sending money to the vendor.

Empirically Speaking . . .

Novice Enhancement: A Technical Perspective

Have you thought about the technical opportunities that may open up if Novice privileges are expanded as proposed in the Federal Communications Commission's PR Docket No. 86-161? If you are not familiar with the details of the Notice of Proposed Rule Making (NPRM), it's worth the time to take a close look at the article, "FCC Issues Novice Enchancement NPRM," on page 48 of June 1986 *QST*. Further information is given in the July *QST* "It Seems to Us... Novice Enhancement Moves A Step Forward." In a general sense, this NPRM and the petitions to which it responds are aimed at making entry-level privileges sufficiently more attractive to: (a) make more people want to become licensed radio amateurs, and (b) retain them as hams by engaging them in not just Morse code QSOs but some voice and digital communications. Whatever new privileges are given to Novices are automatically granted to Technician class licensees. While Technicians already have all-mode privileges above 30 MHz, they stand to gain some new modes in the 10-meter band. So, this package would help recruit some new hams and retain some that might otherwise drop out. But where are the technical opportunities? Let's examine some possibilities:

- If digital modes on the 10-meter band are part of the package, Novices and Technicians could operate radioteletype (RTTY). Also, this could provide the impetus for creation of packet-radio local area networks (LANs) on 10 meters operating at 1200 bauds. With appropriate provisions in the FCC rules, these LANs could have some interface to the developing national and worldwide amateur packet-radio network. Once "hooked" on RTTY or packet radio, it is likely that Novices will want to quickly upgrade to Technician, then to General, to be able to partake of the digital delicatessen that will be available on other bands.
- The proposed digital privileges should be of particular interest to computer hobbyists who might think of Amateur Radio as a "computer peripheral."
- With entry-level operators struggling with digital-communications equipment, it is likely that they will identify problems that more experienced hams simply live with. An example might be a satisfactory solution to accurate tuning of HF packet-radio signals. At present, it is difficult to tune an HF packet-radio receiver because the transmission is not there long enough to make manual tuning an easy job. Experienced HF packeteers build up tuning indicators and otherwise use their skills to cope with the difficulty involved. More "market pull" provided by the Novice packeteers could be the catalyst to get better engineering solutions to problems such as this.
- If Novices and Technicians get new privileges in the 10-meter band, it is likely that this will spur some more 11- to 10-meter transceiver conversions to take advantage of relatively cheap radios. Citizens Band (CB) single-sideband (SSB) radios would be useful for not only SSB voice but could also be used for digital modems. These conversions represent, at minimum, some demonstrated technical ability, at least to follow modification instructions, use the venerable soldering iron, and so forth. If the Novice or Technician undertakes the design and implementation of the conversion, that will demonstrate a higher level of technical capability.
- Adding the 220-225 and 1246-1260 MHz bands to Novice privileges would help us to get the number of users on these bands beyond "critical mass" in most areas. Once numbers go beyond a certain point, the radio manufacturers sit up and listen. Wouldn't it be nice to have a wider variety of radios to choose from in these bands?
- This doesn't sound very technical, but the proposed voice and digital privileges would afford the Novice the more certain possibility of talking on the air to hams with higher class licenses. Also, the new frequencies and modes open up more opportunities for local contacts. What happens next is pretty much up to the people concerned, but chances are that the Novice will become more involved in local Amateur Radio activities—including those technical.
- Accommodating Novices in the 10-meter band will mean some additional spectrum conservation on the part of those already there. One possible outcome could be application of some advanced-technology frequency-sharing techniques for 10-meter beacons. A good place to start is studying the Northern California DX Foundation 20-meter beacon system. Hmmm... What could a packet-radio beacon scheme look like?

As you can see, the Novice enhancement package could be very supportive of advancing technology. The FCC has invited your views.—W4RI

Correspondence

Preliminary ACSSB Test Results Encouraging

On May 4, 1986, I conducted several preliminary ACSSB tests using the STI ACSSB radios to receive signals sent through OSCAR 10. Results, while encouraging, were mixed.

The satellite had a great deal of spin modulation and was moderately weak with most signals running S2 to S3 (S4 to S6 is typical at my location). The ACSSB downlink signal (40 watts to a KLM 18-element 435-MHz antenna) was about S1 to S2, which is approximately a 10- to 13-dB peak signal-to-noise ratio (SNR) on my TR-9000 receiver with the noise blanker turned on.

The STI units do not have a noise blanker because they are often used in a high intermodulation environment where blankers are not usually required. Thus, the peak SNR was around 10 to 13 dB in the STI radio, but noise pulses were equal in amplitude to the voice peaks. Even so, these pulses are suppressed by the action of the pilot AGC system when no speech is present. Thus, the downlink was almost "full quieting" between words even with a noisy signal. During speech syllables, copy was poor.

Furthermore, when local noise increased or the signal deteriorated, there would be an occasional loss of phase lock during nulls whenever spin-modulation nulls occured at the same time as a strong noise burst. This short loss of phase lock was long enough to cause what can best be described as a "burble" in the audio as the PLL searched for a new lock frequency.

Since I have no details on the PLL circuitry design specs, except to note that original lock takes up to 250 ms, I cannot say what the effect of various noise blanking techniques might be on the circuit. Obviously, a "hole punching" blanker might unlock the PLL during the blanked period. Furthermore, since the AGC circuit uses the pilot tone to generate the first level of expansion, loss of pilot for that brief period might generate a positive going gain change which would have the same effect at the output as the noise pulse, itself.

On the other hand, the 250-ms lock-up time suggests that a very brief blanking "hole" might not unlock the PLL because of the time constants involved. If the blanker is placed in the front end prior to selectivity, the incoming pulses will be very narrow (durations of microseconds) and the PLL may not have time to respond to such a brief loss of pilot signal.

Similarly, the time constant in the pilot AGC circuit is on the order of tens of milliseconds. Missing the pilot for even a millisecond might not allow the gain to increase significantly before restoration of the pilot tone after a noise blanking hole.

It looks like I need to research a 21.4-MHz noise blanker circuit for improved 2-meter downlink experiments. A better satellite pointing angle with less spin modulation and stronger downlink signals would help, too!

I don't think this test is fully indicative of what the unblanked STI unit can do with normal signal levels (12- to 18-dB SNR at my location). On the other hand, the 436-MHz downlink should have much less ignition and other pulse-type noises. Another experiment might use a 436/145- or 436/21.4-MHz converter with the STI radio so that we can gain this advantage.

I understand the downlink SNR on this band has a 15- to 25-dB SNR. This should easily give full quieting with ACSSB.

Spin modulation is believed to be less prominent on Mode L. Even during the two-meter test, under poor conditions, the STI radio eliminated all or most of the spin modulation. Having less of it can't hurt, however.

In summary: The first tests of my STI radio through OSCAR 10 met with mixed success. Since these units have no noise blanker, ignition noise, while not evident without speech present, distorted and interfered with the downlinked audio during each syllable. This made the audio slightly worse than normal SSB received on a TR-9000 with noise blanking.

Some question exists as to the effect of a noise blanker on a pilot-tone-based radio. Will it affect the PLL? Will it cause pilot AGC related noise bursts? It should not cause problems because of the time constants of those circuits, but experimentation must be undertaken to prove this.

Use of Mode L's 436-MHz downlink will eliminate most ignition-pulse noise. Thus, the unblanked STI units should perform much better on 436 MHz than at two meters.

A 5- to 8-dB better SNR is usually evident at my location. When the satellite is in a good position with a good pointing angle, it may allow me use of even the unblanked STI unit with good SNR.—*James Eagleson, WB6JNN, 15 Valdez Lane, Watsonville, CA 95076*

From Frequency Counter to Velocity Measuring Device

I wish to convert a spare frequency counter to an instrument for measuring velocity in feet/minute(second). I know how to use the counter as a timer to measure the elapsed time between the beginning and end of an event (eg, a 50-yard dash), but I now use my hand calculator to compute the average over the 50 yards. Instead, I'd like to use my counter to read the average velocity directly so that I no longer need to use a calculator or graph. Can anyone help me?—*Wesley D. Ennis, K7FC, 481 S Higbee Circle, Idaho Falls, ID 83401*

CQ WWVB

I would like to correspond with anyone who has tried to copy WWVB, the 60-kHz radio broadcast station from the National Bureau of Standards, for a frequency reference (or time code) using homemade equipment. I am interested in communicating with those that failed as well as those that succeeded.—*Paul Newland, AD7I, PO Box 205, Holmdel, NJ 07733*

Bits

Assertion: A picture is worth 1,000 words.

If a picture is composed of 500 lines and 500 pixels per line, then: A picture is worth 250,000 pixels.

If 250,000 pixels = 1,000 words, then: each word = 250 pixels.

If a word is worth 250 and there are 6 character spaces per word, then: 250/6 = 41.67 pixels per character.

Thus, if it takes a 5 × 7 dot matrix to make a character, or 35 pixels per character, a picture is really worth: 35/41.67 × 1,000 or 840 words.

But, if you don't like a 5 × 7 dot matrix and feel that a 7 × 9 dot matrix is necessary, then: (7 × 9)/41.67 × 1,000 = 1,512 words equals a picture.

If you don't want to stray too far from the original figure of 1,000 words, then you need to use a 6 × 7 dot matrix, thus: (6 x 7)/41.67 x 1,000 = 1,008 words.

Conclusion: A picture is worth approximately 1,000 words.—*Paul Rinaldo, Editor, W4RI*

Surface Mount Technology

By Ray Miles, KCØBR
13752 Deodar, Tustin, CA

Surface mount technology (SMT) is a relatively new process used in the construction of printed circuit boards. SMT uses a technique of adhering components to the PC board by special pastes and other bonding techniques, rather than through-hole soldering. It is important to the electronics industry and Amateur Radio operators because as its popularity increases, every electronic product will be affected. Japan already uses SMT on 70 to 75 percent of all board applications.[1] Amateur Radio equipment is included in the plan. (Carefully open your Kenwood TH-21, for example, and locate the dual-tone, multifrequency circuit for a visual display of the finished SMT product.)

In this article, SMT processes, their components and substrates, component placement methods, soldering techniques, testing, and problems facing the users of this technology are examined. How SMT will affect the Amateur Radio experimenter can only be argued at this time, since much available equipment continues to be fabricated with leaded components.

Why Surface Mount?

The rationale underlying surface mount devices is best determined by examining the benefits of this technology. Improved electrical performance—as a result of lower lead inductance and faster circuit operating speeds—can be acquired. Automated assembly featuring flexible "pick-and-place" equipment is available. Virtually all surface mount devices can be automatically placed on these machines; they are smaller and lighter than through-hole components and feature a higher resistance to shock and vibration. Most SMT processes can be fully automated. Additionally, SMT involves overall smaller parts (less stock room area required) and smaller equipment (less assembly floor space required). Each of these improvements contribute to lower manufacturing cost.

Components

Most components are becoming increasingly available in surface mount form. Available components include capacitors, crystals, inductors, filters, resistors, trimmer capacitors, thermistors,

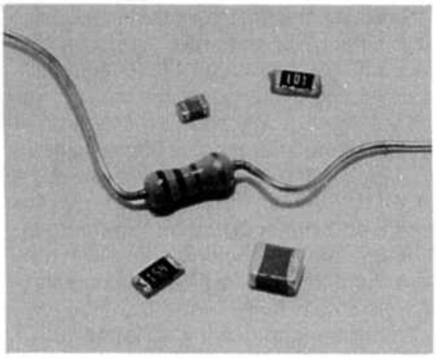


Photo 1—An assortment of microcomponents are compared to a standard ¼-watt resistor. Clockwise from top left, a 0.001μF chip capacitor, package style 0805; a resistor (101 = 10 × 10 = 100); a 0.47 μF capacitor, package style 1210; and a 150-kilohm resistor (154 = 15 × 104).

trimmer potentiometers, small outline transistors (SOT), small outline integrated circuits (SOIC) and leaded- and leadless-chip (IC) carriers. (Small outline describes the size of the transistor or IC. The package can withstand very high temperatures and features "footprints." Footprints on the package are tiny pads that adhere to footprints on the circuit board during soldering processes.)

Components are generally packaged using one of four methods:

- Bulk—these components are loaded into vibratory feeders connected to the automated machines.
- Tube (similar to DIP IC packaging)—they are mounted so as to allow the components to slide down to a pickup point. Tube slides are often vibration assisted.

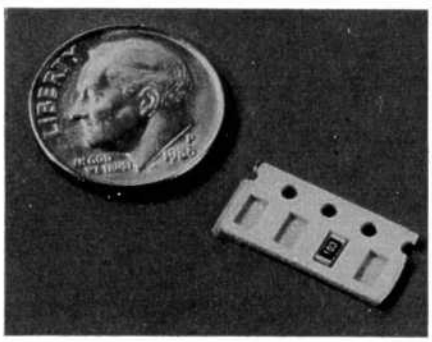


Photo 2—A resistor lies in its 8-mm wide package waiting to be plucked by an automated pick-and-place machine.

- Tape and reel—the tape is fed into a feeder that opens the cover to expose the components, and ratchets the tape into the pickup position. The standard tape size is 8 mm wide, although other tape sizes are becoming standard for larger components.
- Matrix Tray—also called a Waffle Pack because of its appearance. The Tray is made of plastic and the parts fit into each of the tiny pockets.

Substrates

The word substrate is another expression for supportive material or base. It can also be considered a foundation from which a layered circuit board can be fabricated. Two predominant substrate materials commonly used are:

Alumina (ceramic)

The phrase "hybrid circuit" generally refers to SMT on ceramic. Ceramic substrates usually are not larger than 4 inches × 4 inches because larger units may warp during the curing process.

The circuit conductor paths and resistors are deposited onto the substrate with a screen printer that spreads a paste of glass-like material impregnated with conductive or resistive ingredients. The substrate is then placed in a dryer to evaporate the volatile paste vehicles. Repeating the previous two steps, additional layers may be screen printed onto the substrate and dried (I have seen as many as forty layers printed onto a well-designed substrate.) After all the layers have been printed, the substrate is placed in a furnace to be fired.

During firing, the dried paste melts on the substrate and actually becomes part of its surface. After this process, the resistors that are required to be low-tolerance devices are laser-trimmed to value.

Glass Epoxy

Glass epoxy boards (standard circuit boards) are treated essentially the same for SMT as they are for through-hole circuits, except for trace and hole dimensions and solder mask requirements. Current state-of-the-art techniques produce 0.005- to 0.007-inch traces and 0.010- to 0.015-inch holes. The technological goal is to soon manufacture 0.002- to 0.003-inch traces, and 0.006- to 0.007-inch plated-through holes. The purpose of these small holes (called VIAs) is not to allow passage of part leads, but

[1]Notes appear on page 6.

rather to provide circuit paths between the top, bottom and intermediate layers of the board.

The Solder Mask

There are two predominant types of solder mask—the wet mask and dry film. The wet mask method is the most common and the least expensive solder mask to produce. A liquid is screened onto the PC board and then dried in much the same way that designs are silk screened onto a T shirt. This method is not accurate for most surface mount boards because the liquid does not hold its consistancy or position tolerance well.

Dry film uses a thin plastic-like material that is supplied in sheet form. It is bonded to the PC board and photographically exposed and developed. The result is a precise and uniform solder mask.

The copper on a PC board may be tinned with solder before or after the solder mask is applied. If the solder mask is applied over tinned copper, when the board is wave or reflow soldered, the thin layer of solder under the mask becomes molten. This allows the mask to move and additional solder may flow under the mask. (You may have seen the bottom of a PC board that has wrinkles over large areas of masked tinned copper.) In wave solder, having the solder get under the mask and into the solder joint is not a problem. In surface mounting, it is a different story.

During the surface mounting process, a precise quantity of solder paste is applied to the solder joint. If some of that solder flows under the mask during reflow, there will not be enough solder left at the joint. If the PC board is solder tinned after the solder mask is applied (solder mask over bare copper or SMOBC) these problems are eliminated.

Component Placement

Component placement can be done by simply using tweezers to pick up and position components. This method may be adequate for boards with few parts, but as part quantities increase, the chance for error also increases rapidly. This leads to the next method: Semi-automatic placement.

With semi-automatic placement, an operator sits at a placement machine with a vacuum stylus in hand. The machine turns on a light at the correct component bin, and also shines a light on the substrate, thereby identifying component location and polarity. The operator merely has to "follow the lights" to construct the board.

Another system uses a fully-automatic pick-and-place machine. One or more placement heads on a machine using an X-Y positioning system contain different stylus sizes. The styli can be changed automatically, each capable of handling a limited range of component size. Multiple head/stylus sizes are preferable. Head utilization is not limited to parts placement: One of the heads may be a dedicated epoxy dispenser.

Next is a more "component-size-dedicated" system. Here, the tradeoff is flexibility for speed. The placement head is fixed and the circuit board is moved. The component input magazines move to a fixed pickup point, or a shuttle brings the component to the pickup point. The part is put onto the placement head, the board is moved into position and the head puts the part onto the board.

Fastest and most costly, is the mass-placement method. The magazine is loaded with components that are pre-oriented exactly as they will be placed onto the board. The multi-stylus head picks up and places all parts in only one operation.

Clearly, the mass-placement method is the most efficient system. However, considering the dedicated tooling required, this system is only a viable candidate for high-quantity consumer product lines.

Soldering

Two major soldering methods are used in SMT:

Solder wave

The components on the bottom of the board can be soldered with a dual-wave flow solder system. Components soldered in this manner must be cured (glued to the board with epoxy) before proceeding to wave solder.

Dual-wave soldering is a system whereby the board travels through a first wave that is turbulent (mostly vertical speed component) and then travels through a second wave that is the usual, smooth type (horizontal speed component). The first wave gets the solder into areas that the normal wave may miss; the second wave smooths out the solder, removing most of the "icicles" and bridges.

Presently, there exists in the industry some controversy as to whether a "hot-air knife" is also required. The hot-air knife is a device that follows the dual wave. It creates a narrow, high velocity air jet at a temperature above that of molten solder. The air jet blows away icicles, bridges and excess solder.

Reflow

This process applies intense heat to an area previously loaded with solder paste and components. The heat causes the solder to reflow and creates solder joints. The solder is usually deposited with a screen printer.

Infrared and vapor phase techniques are also used in reflow soldering. In the infrared method, the board is transported on a conveyor through multiple heat zones. The temperature in the first few zones is set low to evaporate existing paste fluids. The final zones heat the board to a temperature at which the solder reflows.

The vapor phase method also requires that solder paste fluids be evaporated from the board before reflow. Then, the assembled board is immersed into a hot, saturated vapor generated by a pool of boiling Fluorinert.[2] As the hot vapor condenses onto the board, it releases the latent heat of vaporization. The colder the part, the more the vapor is condensed on it; the hotter the part, the less condensation. Therefore, heating transfer is rapid, uniform, and relatively independent of component geometry. One drawback of this process is that components become more prone to misalignment because of liquid condensation on the work piece surface.

Testing

If an in-circuit component test is to be performed, this should be considered during the initial board layout design. Solder pads with surface-mount components often do not lend themselves to "bed-of-nails" test fixtures. Test fixtures are available, however, such that the board fits in vertically. Contact plates on both sides of the board possess bed-of-nails test fixtures, but even with this arrangement, there may be test nodes inaccessible to the test nails.

Wherever possible, the board should be manufactured with VIAs to provide contact points to test points otherwise located in an inaccessible area of the board. The best situation is to have all test nodes on the top of the board, brought down to the bottom of the board by the use of VIAs.

Actual inspection, testing and repair of SMT boards can be performed visually, by X-ray or by laser. A heated collet can be used to solder or unsolder only one component. Let's say that a replacement chip must be inserted. The new component is aligned with its position on the board, and solder paste is applied to the bottom of the chip. Then, the chip is placed on the board and a heating element inside the collet walls applies intense heat until the solder reflows. While the collet is lifted from the work area, a center pin holds the replacement part in place until the solder is cool.

Another device used for manual removal or insertion of a component is a heated probe. With a handle shaped like scissors, this tool is heated like a conventional soldering iron. The component-handling end is sized to fit the four sides of a chip carrier, and several sizes are available.

Another system uses a hot-air repair terminal to apply a stream of air to the component connections, while a tweezer-like tool removes the component. Nitrogen, nitrogen and hydrogen, argon or an infrared light that concentrates heat on a certain area is also used in a similar process.[3] These inert gases are used to reflow the solder so a faulty component can be removed. This process keeps oxidation to a minimum.

Problems

Because most chips consist largely of ceramic substrates, the components made of this material must always be watched for signs of thermal stress. Ceramic has a relatively low coefficient of thermal expansion, compared to that of glass-epoxy circuit boards. During heating and cooling cycles, the expansion differences tend to place a strain on the solder joints. Uneven solder fillets (concave junction formed by the solder between the component pad and the circuit board pad) multiply this problem.

For example, we may have a component that has a large fillet on one side, and a small fillet on the other side. With thermal expansion, the large fillet may hold while the small fillet gives a little. Instead of both fillets sharing the strain evenly, the small fillet receives nearly the entire strain.

This can be a significant problem with large parts. One solution to this problem is to use leaded chip carriers, SOTs and SOICs. With leaded parts, the leads absorb most of the thermal stresses.

Tombstoning and Solder Balls

Fluids may remain in the solder paste during the solder reflow process. When this occurs, the remaining fluid boils out of the paste, creating minute explosions that can blow one end of a component upward from the board. This causes the component to stand on one end, an effect known as "tombstoning." Tombstoning may also occur if one side of a component is in the solder paste and the other side is not, or if the paste on one side melts before the paste on the other side does. Solder surface tension pulls the part to a vertical position. Surface tension is not always a bad thing! During reflow, solder surface tension may serve to pull the parts to the center of their solder pads (if the pads are well designed) aiding alignment of the component.

Let us return to the first reason for tombstoning (fluid remaining in the solder paste during reflow). Its mechanism (minute explosions) also creates solder balls. The explosions throw small bits of solder paste over other parts of the board. When the paste melts during reflow, balls of solder form as a result of surface tension.

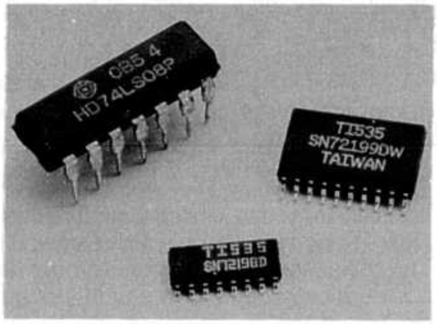


Photo 3—Three integrated circuits. A standard 14-pin IC is shown in the upper left hand corner. The remaining chips are small outline integrated circuits (SOICs). Their pins are shaped in a "gull-wing" fashion (flared) for placement on the circuit board pads to which the ICs will be adhered. SOICs have the same pinouts and electrical specifications as DIPs of the same generic number.

Conclusion

In this article, we have discussed the specifics of what SMT is and the manufacturing processes involved. You might ask, "If the technology proves itself, and has overall advantages compared to the conventional way of fabricating printed circuit boards, why then, is SMT use not more widespread?" There are several concerns manufacturers must address before converting to SMT. New equipment to perform SMT functions would have to be installed. This costs money. Employees who have been educated to manufacture design boards and use through-hole soldering and mounting techniques would have to be reeducated. Again, this costs money.

What impact will this new technology have on Amateur Radio? Should the experimenter be concerned? Yes. Pat Hawker, G3VA, calls SMT "throwaway electronics." If a faulty piece of equipment needs modification or repair, how does the experimenter go about fixing it? An SMT printed circuit board would have to be sent back to the factory, or even worse, disposed of entirely. Faulty components would be difficult to trace on densely-packed boards, and some surface mount devices are too small to carry identification marks or values. This is definitely not technology for experimental breadboard units, G3VA opines.[4]

SMT could be beneficial to the Amateur Radio experimenter as well. Companies using SMT can afford to pass on their production savings to the buyer. Result? Low-cost equipment. If a single device is faulty and traceable, hand tools might be made available to designers and as easy to obtain as a soldering iron is today. Educational facilities might include courses of study on SMT for engineering students. These are only some of the many possibilities that can make SMT work for Amateur Radio. The results of one survey predicts that US manufacturers would not become greatly involved in SMT until the 1990s—but that's not a long way off.[5]

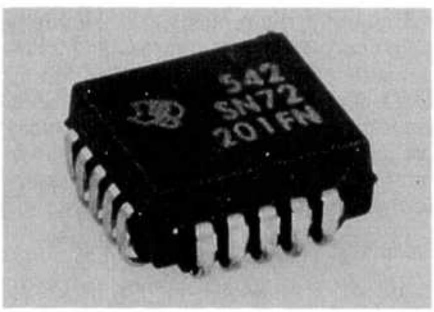


Photo 4—A 20-pin PLCC (plastic leaded chip carrier). The chip leads curve back under itself for ease of placement on the footprint pads. The PLCC is also referred to as J leaded because the curved lead configuration resembles the letter J.

Notes

[1]Jerry Lyman, "What's Holding Back Surface Mounting," *Electronics*, Feb 10, 1986, Vol 58, No. 6, pp 25-29.
[2]See note 1.
[3]Jerry Mullen, *How to Use Surface Mount Technology*, (Dallas: Texas Instruments Information Publishing Center), 1984.
[4]Pat Hawker, "Technical Topics," *Radio Communications*, Mar 1985, pp 188-187.
[5]See note 1.

Bits

The C Primer

If you are familiar with computer programming and are interested in learning the C language, get a copy of *The C Primer*. Written by Les Hancock and Morris Krieger, there are over 100 complete program examples to illustrate important points. This 303-page book is a second edition of a popular guide and six new chapters have been added. Topics include bit fields and masks, the development of a line-by-line sorting program, the C preprocessor, structures and unions, and file I/O.

For a copy of *The C Primer*, write to McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020; tel 212-512-3493. The price is $17.95.—*KA1DYZ*

The Xerox 820-1 Compendium—Part 2

By Andre Kesteloot, N4ICK
AMRAD, PO Drawer 6148,
McLean VA

Smoke Test No. 1:

After you have obtained some of the parts mentioned in part 1 of this Compendium, test the switching power supply.[22] Check that the input strap (if any) is set for 110 V. Connect some wire-wound resistors to the various output lines (150 ohms between each of the 12-V lines and ground, and 5 ohms, 5 watts on the 5-V line). Turn on the power supply and measure the voltages to be sure they are correct. (Without a load, the switching supply will not produce the correct voltages.) You may want to let the power supply "cook" for several hours, but it should remain cool. Two potentiometers are available (one on some models) for making adjustments. One is used to adjust the output voltage of all the lines simultaneously, and the other serves as the overcurrent protection. Note that if the control for the overcurrent protection is backed off too far, the power supply will not be able to handle the starting load when the disk drive is activated, and the diskette will not boot.

Smoke Test No. 2:

If everything appears in order, connect the power supply, keyboard and a video monitor to the board. (The pin out and Dave Borden's, K8MMO, suggestions for these two cables will appear in another part of this Compendium.) When power is applied, the following message should appear on the screen:

...XEROX 820 VER. 2.0...
A - BOOT SYSTEM
T - TYPEWRITER

If something else appears on your monitor, push the reset button on the board's back panel. Type A. The screen should display: "disk error 80 UFF TOO SOO." This occurs because a disk drive is not connected. If you type T, the Xerox computer will lock and you will have to reboot the system. The "typewriter" option would operate if a printer were connected to the board. The original purpose of this command was to allow text typed on the keyboard to be sent directly to the printer: ie, an address on an envelope. This text does not appear on the video monitor.

Smoke Test No. 3:

To test all the RAM memory chips, type: XOOOO,EFFF<RETURN>. The screen will show a "+" sign for each memory location successfully checked. On initialization, the monitor routine that resides in ROM loads itself in RAM locations FOOO through FFFF, from where the test is run. Testing that portion of RAM should not be attempted. To test each location takes about 3 seconds. This is a good time to let the computer run for 72 hours.

If a bad memory chip is present, a message such as:

AAAA DD should = XX

will appear. AAAA is the bad memory location, DD is the data read, and XX is the data written there during the test. If such a message appears, locate the faulty chip and replace it. Cut the chip pins as close as possible to the chip. The pins can be removed from the board using solder-wick and a fine-tip soldering iron. Install an IC socket and insert a new 4116 chip.

Smoke Test No. 4:

Turn everything off and connect the disk drive(s). If you have only one drive, the 150-ohm termination resistors should be in place on the drive. (These terminations are about the size of a microchip. On some drives they are actually encapsulated in a DIP module.) If you have two drives, these resistors should be removed from drive 1 (A). The resistors on drive 2 (B) should be left in place. Also, the microswitches or straps should be configured so that the correct bit is selected for each drive: This is what tells each drive whether it is A or B. (I call the first drive "1" or "A" and the second drive "2" or "B". Radio Shack calls its first drive "0" and its second drive "1".)

Insert a SSSD (single-side single-density) CP/M® diskette in drive 1 (A) and type A <RETURN>. The screen will display the following message:

CP/M REG TM 2.2 SY 3.00
A>

Congratulations! Half of your headaches are over! Type DIR <RETURN>: The CP/M software on that diskette will be listed on the screen and you should be able to run it. (Refer to the CP/M Primer for more details.)

To use both sides of the diskette, modify the BIOS portion of your CP/M (per Dave Borden's, K8MMO, article in an upcoming installment).

If you are experiencing disk-drive problems, see note 23. Before incriminating your disk drives, remember that excessive heat tends to warp the diskettes, whereas if the air is too dry, you could encounter electrostatic problems. Now that your computer operates properly, Terry Fox, WB4JFI, and David Borden, K8MMO, offer application suggestions for your Xerox board.

The Xerox 820 Big Board

By David W. Borden, K8MMO, AMRAD

During 1985, Xerox sold a single-board computer (similar to the Texas Big Board) for $50. By the end of April, they were sold out! Many AMRAD members bought an 820, but were faced with one problem—how to get them working. Briefly describing the Xerox board: It has a Z80® central processing unit, 2-kbyte EPROM, 64-kbyte of memory, floppy disk controller, SIO (one user port and one printer port) and video and keyboard circuits. I connected a monitor, keyboard, floppy disk and power supply to my board and doctored it to working condition. My board arrived with a bad memory chip. I applied video modifications that I received from R. Dunbar, WØPN. I am providing this same information here so that you may get your board operating. First, I obtained the documentation from Ferguson Engineering, PO Box 300085, Arlington, TX 76010. They offer many other products for the Xerox board such as the CRT connector, CBIOS source, and so on. Write for details.

Xerox Video Modifications

Obtain a 10-pin video connector. You can either buy it or make one by taking a standard floppy disk cable connector (one that goes on the controller end) and cut it with a hacksaw or file it to 10 pins. These connectors are 0.1 inch pin to pin and 0.1 inch row to row. I used the hacksaw technique because I had extra floppy connectors.

I took the Zenith ZVM131 monitor that I used with my C 64 and connected it to the Xerox board. It had RGB input and separate horizontal and vertical sync inputs which is what Xerox provides. Correct the overscan by changing R10 from 180 kilohms to 22 kilohms, and R11 from 47 kilohms to 82 kilohms. If you have

[22]Notes appear on page 8

a monitor similar to my Zenith, connect the horizontal sync from the Xerox to positive horizontal sync input on the monitor. Link the vertical sync to the negative vertical sync on the monitor, and connect the video output from the Xerox to either RED, BLUE, or GREEN input on your monitor. The Xerox operates with +12, -12 and +5 volts (at 3 to 5 amps). Applying the power is another problem. The Molex® connector is a 9 pin type, available from many sources. I borrowed a matching power supply. If you use a monitor like mine, connect the floppy and go to work. If not, produce composite video as follows:

1. Remove R58, 150 ohms, near pin 7 of J1.
2. Remove R60, 150 ohms, between U106 and U117 near U105.
3. Cut trace from U117-10 near the pin on the bottom of the board.
4. Solder a 39-ohm resistor (use insulation tubing) between U117-10 and the right hole from where R60 was removed (it goes to J7-5).
5. Using one lead of a 100-ohm resistor, jumper J7-3,4,5 together and connect the other end of the resistor to J7-10 (ground).
6. Reverse the horizontal sync polarity by cutting trace to U15-4 (on top of board) between that pin and the adjacent feedthrough. Route a feedthrough to U15-13.
7. Check your sync pulse lengths. HSYNC should be 5.0 μs and VSYNC should be 400 μs.

When the Xerox board is converted to produce composite video, the display may "swim" slowly from side to side. This is because the vertical oscillator frequency is 58.76 Hz rather than 60 Hz, and this oscillator "beats" with the 60-Hz line frequency, causing the swimming video. This can be fixed with the following modification:

1. Cut the trace from U36-2 to U53-5.
2. Add a jumper from U36-2 to U53-4.

This changes the vertical frequency from 58.76 Hz to 59.96 Hz. This is a very simple modification, and can even be done on the top of your board if you already have it installed in a case.

You will now have composite video on J7-3,4,5 and ground on J7-8,9,10. Dunbar advises that if you have dc coupled input on your monitor, you may wish to couple the video through a 100-μF capacitor shift in the black level. He recommends a Zenith ZVM-122A amber/green monitor.

Xerox 820 Software

Concerning software: The CBIOS can be purchased from Ferguson Engineering. Install the new CBIOS on your current CP/M (you should buy another copy to use on this board). This gets you up and running using DDT and SYSGEN to get the board onto tracks 0 and 1 of an eight-inch disk. Boot the system by typing an "A" after pressing the reset switch. The Xerox 820 is a great buy and a quick way to CP/M.

The 820 and Packet Radio

By Terry Fox, WB4FJI, AMRAD

Latest Development Hardware

One agreement made at the 1985 ARRL ad-hoc digital committee was to standardize on the surplus Xerox 820 computer boards for developing network layer systems. These boards were available from the Xerox surplus center in Texas, in an assembled format, but not guaranteed. They make a great inexpensive computer to be run on packet radio.

AMRAD has received a disk that contains Z80 assembly language routines to make our Xerox 820 into a full-blown X.25 DTE device, including levels 1, 2 and 3. This code was written by Eduardo Elizondo, and is available on a noncommercial-use basis. We are looking into modifying this code to support the Amateur AX.25 protocol.

Another way to make the 820 packet is to remove the PIO chip, and install a daughter board that has a Zilog 8530 SCC chip on it and some timing logic. This board was designed by Howard Goldstein, N2WX, of the Florida Amateur Digital Communications Association (FADCA), and is being made available by Tucson Amateur Packet Radio (TAPR).[24,25]

I am using one of the Xerox boards, and have added a new level of hardware to it. I have placed an AMD 7910 world modem chip on another board that fits above the N2WX daughter board. This chip is driven by channel B of the SCC chip and works great as long as a squelched radio is used (the 7910 carrier-detect logic is easily fooled by noise).

The 8530 SCC is the same chip I am using in the design of the AMRAD PAD. The use of the SCC on the Xerox 820 may help the PAD tremendously. I can now generate and debug code on the Xerox under CP/M, and move it to the PAD when debugged. This eliminates a lot of EPROM burning. The main problem with the PAD is that there has been no code for it, but now there may be a way out.

Part 3 of the Xerox 820-1 Compendium will appear in the August issue of *QEX*. An article and the schematic diagram for a Xerox packet interface board will be featured, and K8MMO discusses the Xerox 820 packet radio software.

Notes

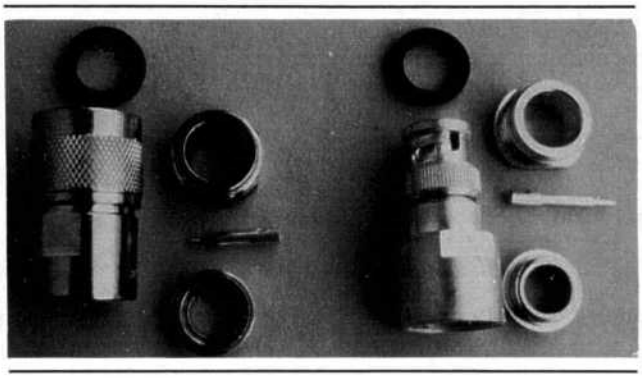
[22] A. Kesteloot, "Xerox 820-1 Compendium," *QEX*, Jun 1986, p 7.
[23] M. Mlinar, "The Xerox Column," *MicroCornucopia*, Apr-May 1985, no. 23.
[24] FADCA, 812 Childers Loop, Brandon, FL 33511
[25] TAPR, PO Box 22888, Tucson, AZ 85734

Bits

Nemal Offers New Connector Line

Nemal Electronics International of Florida has introduced a new line of connectors designed to fit the Belden 9913 and 8214 type cables. The connectors are available from stock both type N (part no. NE720) and BNC (part no. NE860) series and will accommodate the 9-1/2- to 11-gauge center conductors in these and similar cables.

Both series of connectors meet the electrical and mechanical requirements of MIL-C-39012 and incorporate silver-plated contacts and Teflon insulation. Each is fully compatible with other standard connectors in its series. For further information on this line of connector, contact Nemal Electronics International, 12240 NE 14th Ave, North Miami, FL 33161, tel 305-893-3924.—*KA1DYZ*



(Photo courtesy of Nemal Electronics Intl)

Additional Sweep-Frequency Impedance Measuring Techniques

By Ken Simons, W3UB
2035 Willowbrook Dr,
Huntingdon Valley, PA 19006

A delay line used with a sweep-frequency generator for impedance measurement and circuit adjustment provides a powerful measuring tool that is most useful for wide bandwidths. But, when the impedance to be measured is part of a resonant system with a bandwidth less than about 10% of the center frequency, the delay line technique is less useful. The long line necessary to get the needed resolution has so much loss that measurement accuracy is reduced. The following techniques are particularly useful with narrow-band circuits.

Measurement By Bridging Loss

Basic transmission line theory states that the impedance seen looking into a section of line that is terminated at the far end in its characteristic impedance *is* the characteristic impedance—a pure resistance for low-loss lines. Fig 1A depicts this situation. Similarly, the equivalent circuit seen looking back into a line fed from a matched source is a constant voltage in series with a resistor equal to Z_0 (Fig 1B).

It follows that the circuit seen at any point along a matched system where the line from the source joins the line to the load is equivalent to a resistive source feeding a resistive load. Fig 1C shows that when a given impedance is "bridged," (connected across an otherwise matched system), the loss of energy transferred to the load is the same as the loss that is calculated when bridging that same impedance across the load in the equivalent circuit.

In the general case where the unknown impedance has resistance and reactance, it is necessary to know the magnitude and phase angle of the loss introduced so the unknown constants can be determined. Where suitable equipment is available to measure both quantities, a chart relating them to the constants of the bridging load can be referenced.[1]

In many practical situations, the unknown is either a pure resistance or a pure reactance. In these cases, the magnitude of the unknown is determined by a simple attenuation measurement: The relationships can be calculated as shown in Appendix 1, and the results drawn as nomographs to relate bridging loss to attenuation. Two such charts are illustrated in Fig 2 (for systems with 50-ohm impedance) and Fig 3 (for 75-ohm systems).

Measurement By Series Loss

Bridging is not the only way in which an unknown impedance can be connected into a matched system. It is also possible to open the center conductor at a junction and insert the unknown in series, as indicated in Fig 4. Fig 4A shows the actual circuit for the measurement technique for a series loss circuit; Fig 4B displays the equivalent form.

The loss that is introduced in the circuit is a measure of the impedance in this case also. For unknowns that are purely resistive or purely reactive, the loss can be calculated (see Appendix 1) and the resulting relationship drawn in the form of nomographs (Fig 5—series loss in 50-ohm systems; Fig 6—series loss for 75-ohm systems).

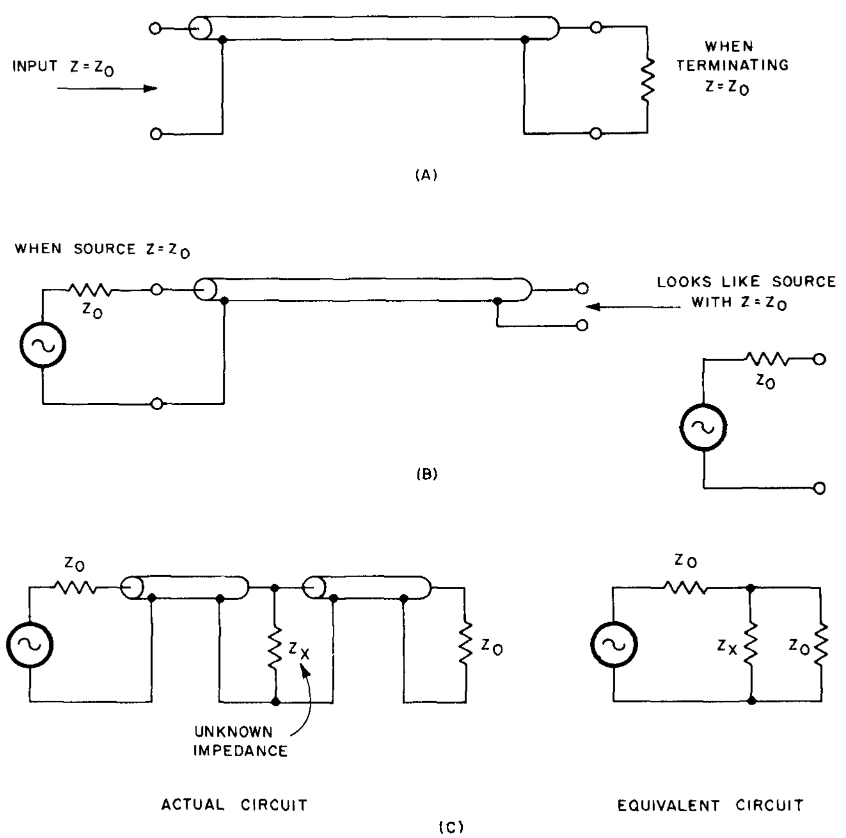


Fig 1—At A, the input impedance sees the terminating impedance in a low-loss line as a pure resistance. B shows the equivalent circuit of that in A; looking back into the line fed from a matched source, the circuit acts as a constant voltage in series with a resistor equal to Z_0. In C, a given impedance Z_x is connected across a matched system and the actual circuit exhibits the same energy loss to the load as that calculated when Z_x is across the load in the equivalent circuit.

[1] D. A. Alsberg, "A Precise Sweep-Frequency Method of Vector Impedance Measurement," *Proceedings IRE*, Nov 1951, pp 1393-1400.

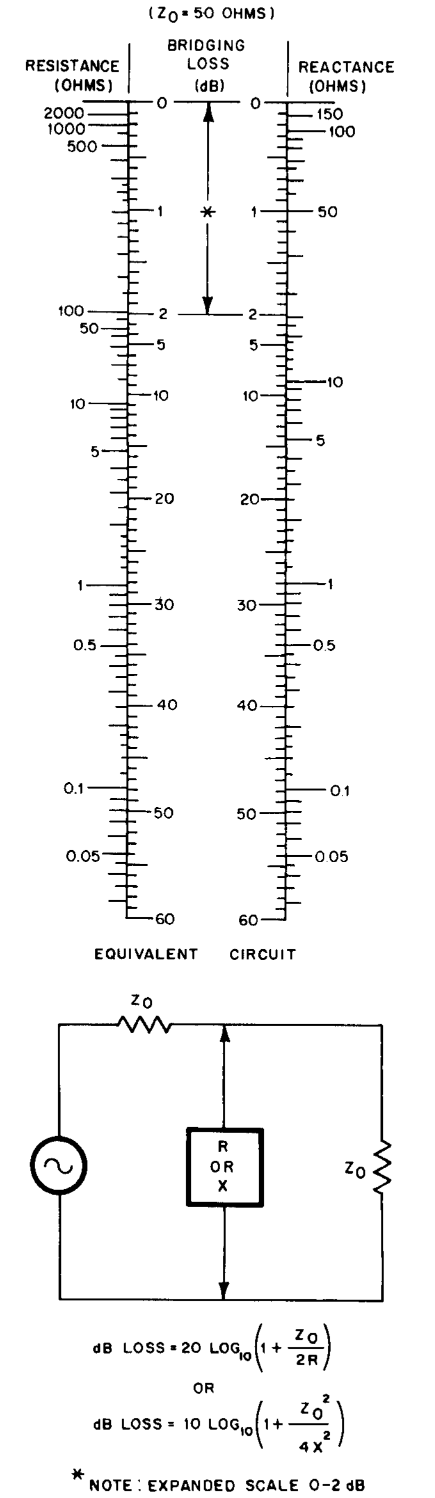


Fig 2—A bridging loss nomograph for a 50-ohm impedance system.

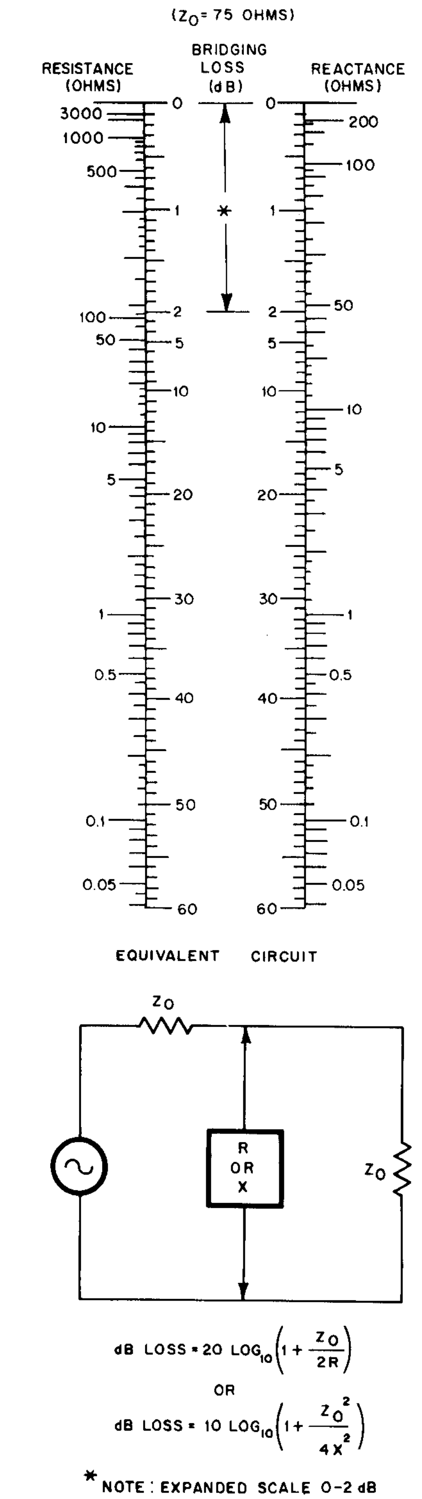


Fig 3—A bridging loss nomograph for a 75-ohm impedance system.

Technique

Certain precautions are essential if reasonable accuracy is to be attained:

• Accurate impedance measurement depends on accurate attenuation measurement. The comparison technique, diagramed in Fig 7, is recommended. In this setup the loss in one branch, containing the unknown, is compared with the loss in the other branch, which contains an accurate variable attenuator. The use of carefully matched fixed attenuator pads with 5 or 10 dB loss at the points indicated in Fig 7 guards against impedance mismatch in the associated equipment and increases measurement accuracy. The use of such pads is possible only where the unknown has moderate loss, or where the measuring setup includes a high-gain RF amplifier.

• Refer to the illustrations in Fig 8. Any convenient physical arrangement may be used for a test jig provided that the system characteristic impedance is maintained. Two connectors mounted on a metal sheet can be used. The dimensions of the sheet should be several times the spacing of the connectors to minimize stray couplings from the circuit under test to the rest of the universe. Connect the unknown between the strap and chassis ground. If the unknown circuit is coaxial, such as a short piece of cable, attach it to the junction with a "Tee" connector. The strap inductance must first be adjusted for best impedance match without the unknown.

• Harmonics or other spurious components in the output of the sweep-frequency generator can cause errors, particularly when the unknown gives an attenuation maximum at resonance. Fig 9 illustrates some techniques that can be used to minimize the effects of spurious signals. When the measurements are being made within an octave band, a low-pass filter cutting off at the upper end of the octave can be used to reduce harmonic errors (Fig 9A). Where there is a choice of circuit configuration, using an arrangement that gives attenuation minima at resonance will help to reduce the effects of harmonics (Fig 9B). Finally, a tuned amplifier or receiver of moderate bandwidth (a television or radar receiver) can be installed after the test jig to minimize harmonics and to increase the gain of the system (Fig 9C).

Applications and Examples of Results

Measurement of Tuned Circuit Q

Refer to Fig 10. A convenient way to measure the unloaded Q of a resonant circuit is to determine its resonant resistance by the bridging or series loss method. The Q is then found by comparing this resistance with the reactance of either reactor at resonance, calculated from a known L or C value. The choice as to the use of the bridging or series connection, and series or parallel resonance, is determined by the impedance level and physical configuration of the circuit being tested. As an example, a coil space-wound with 15 turns of no. 16 copper wire was connected in series with a 15-pF high quality ceramic capacitor. Its bridging loss as a series resonant circuit connected across a 75-ohm system was 31 dB at 35

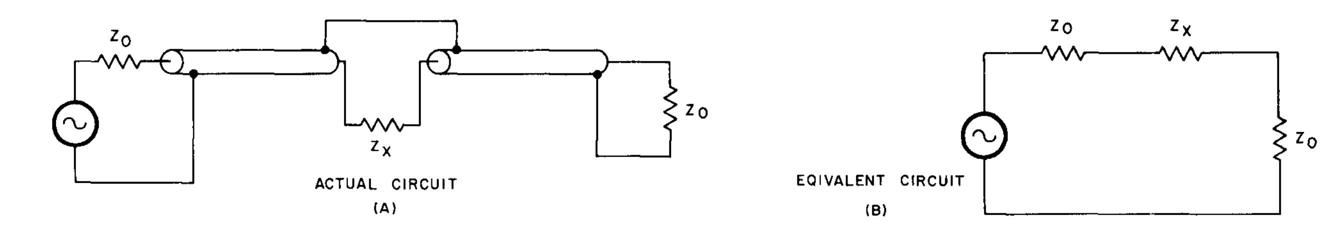


Fig 4—Measurement by the series loss method. The actual circuit is shown in A, and B depicts the equivalent circuit.

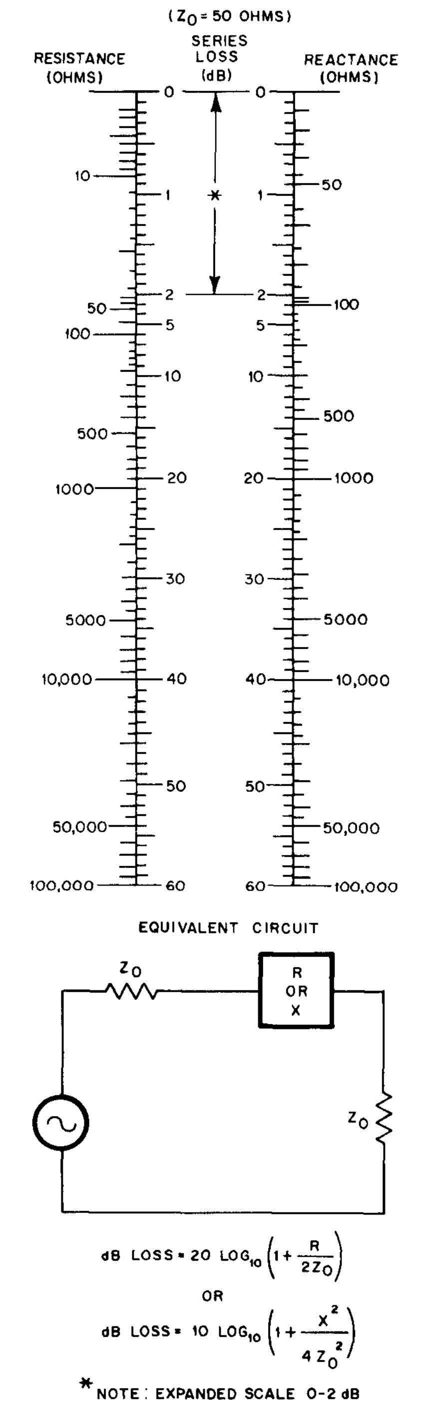


Fig 5—A series loss nomograph for a 50-ohm impedance system.

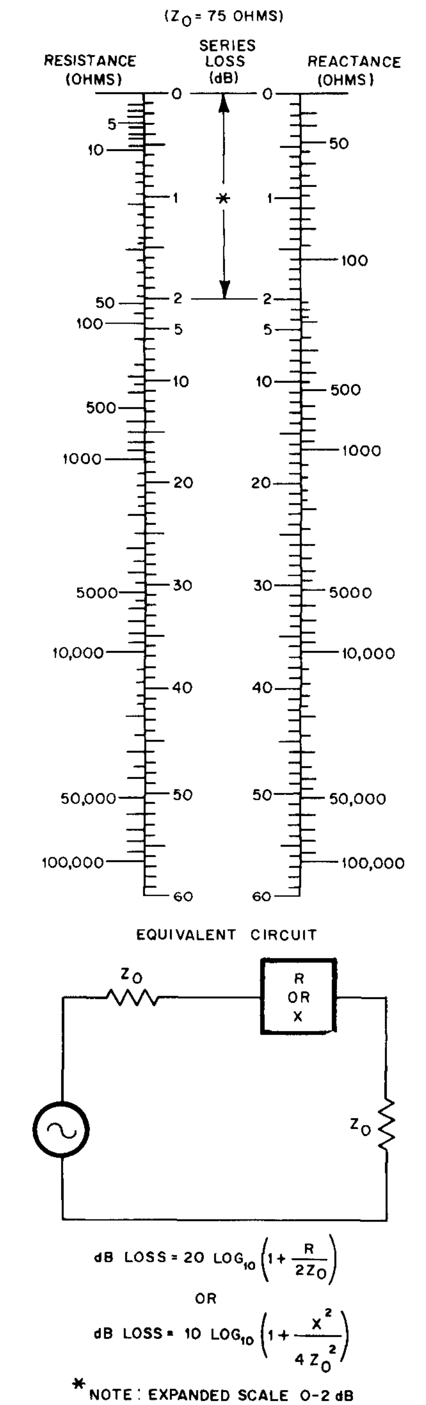


Fig 6—A series loss nomograph for a 75-ohm impedance system.

MHz. From the chart in Fig 3, this indicates a series resistance of 1.1 ohms. The reactance of 15 pF at 35 MHz is 303 ohms, so the circuit Q was 303/1.1 or 275.

Measurement of Attenuation of Short Cable Samples

The input resistance seen looking into a short section of transmission line that is open or shorted at the far end is a function of the loss of this line section. Using a coaxial measuring system, the input resistance of a resonant section of coaxial line can be measured best by the bridging method (Fig 11). The measured resistance is directly related to the attenuation of that line section, and can be used to calculate it (see Appendix 2).

For example, the input resistance of a three-foot section of RG-6 coaxial cable left open at the far end was measured by the bridging method. It produced a bridging loss of 31 dB at its quarter-wave resonant frequency of 160 MHz. From the chart (Fig 3), the 31 dB point corresponds to a resistance of 1.1 ohms, giving an attenuation for this sample of $10 \log_{10} 75 - 1.1/75 + 1.1$ or 0.12 dB; a loss of 4.0 dB per 100 feet.

The Input Impedance of a Vacuum Tube

The input impedance of a vacuum tube at high frequencies can be measured by making this impedance part of a series resonant circuit. To do this, connect an inductor in series with the grid terminal. Connect the other end of the inductor as a bridging load across the measuring circuit. This allows rapid determination of the bridging loss, and thus of the total series resistance (see Fig 12). The measured resistance includes the losses of the inductor R_L as well as those of the tube R_{in}. R_L is small if a high Q inductor is chosen, but it can be measured accurately by replacing the tube with a high-grade air trimmer set to give resonance at the same frequency, and measuring the bridging loss of the resulting circuit.

When measuring the input resistance of a tube by this method, it is notable that the measured resistance is only slightly affected by frequency. The results of measuring the input impedance of a 6CY5 tube with three different inductors are shown in Table 1.

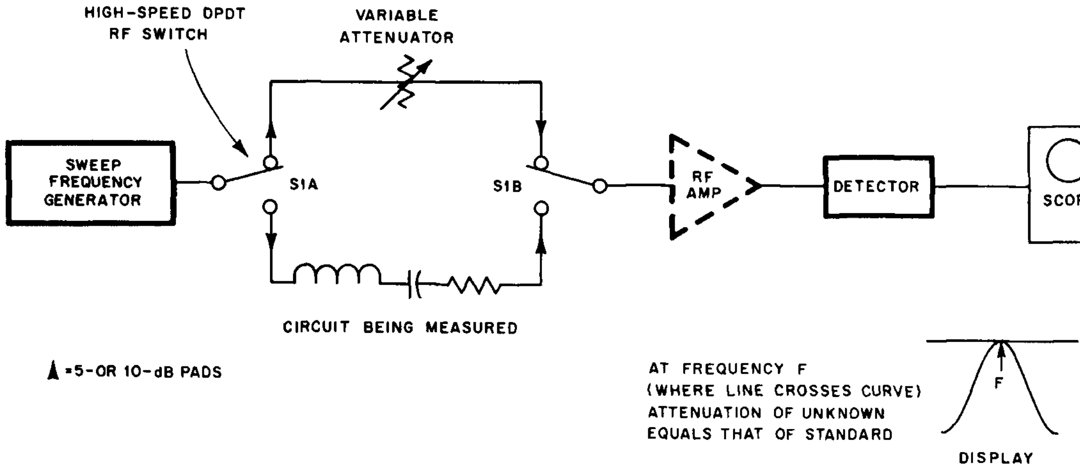


Fig 7—A technique for accurate attenuation measurement. Five- or 10-dB pads at points marked by an arrow increase measurement accuracy by improving the impedance match. An RF amplifier may be needed to measure high attenuation.

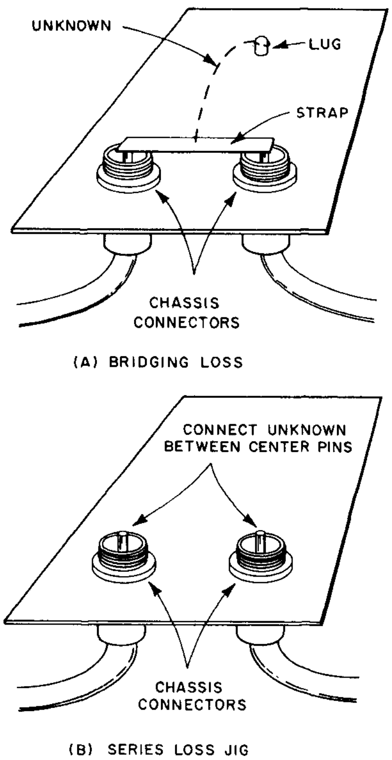


Fig 8—Test jigs are used to connect an unknown between the strap and chassis ground. At A, a bridging loss fixture is set up. The strap inductance is adjusted for the best impedance match without an unknown. B shows a series loss jig.

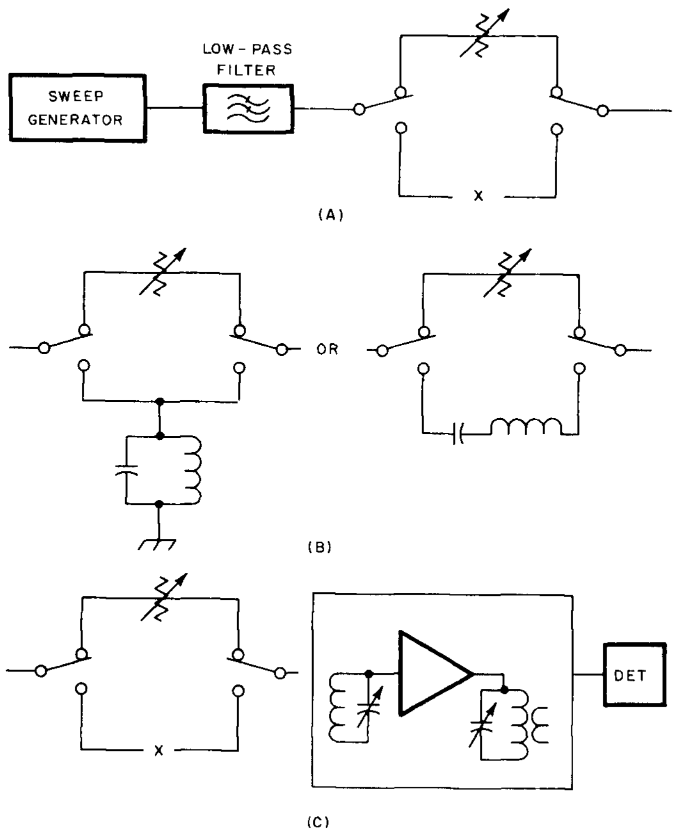


Fig 9—Three different circuit arrangements can be used to minimize errors due to harmonics. A shows the use of a low pass filter, while B shows two configurations to offer minimum attenuation at resonance. C displays a tuned amplifier or receiver following a test jig.

Table 1

Inductance	15.5 mH	1.08 mH	0.1 mH
Resonant Frequency	14.15 MHz	54.3 MHz	188.0 MHz
Bridging Loss	12.0	14.3	13.3
Series R	12.5	9.0	10.0
Coil R	5.9	1.9	0.6
Tube R	6.6	7.1	9.4

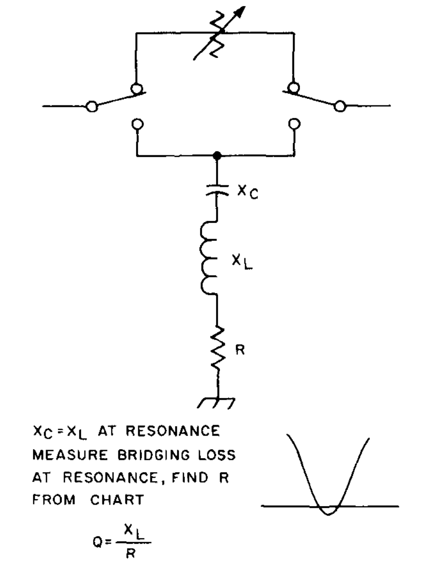


Fig 10—A component configuration for measuring the Q of a circuit.

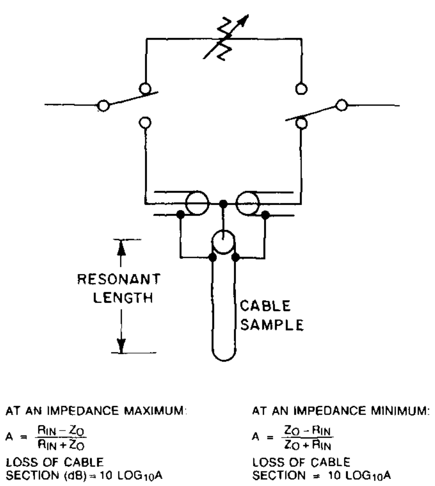


Fig 11—Measuring the loss of a short cable section.

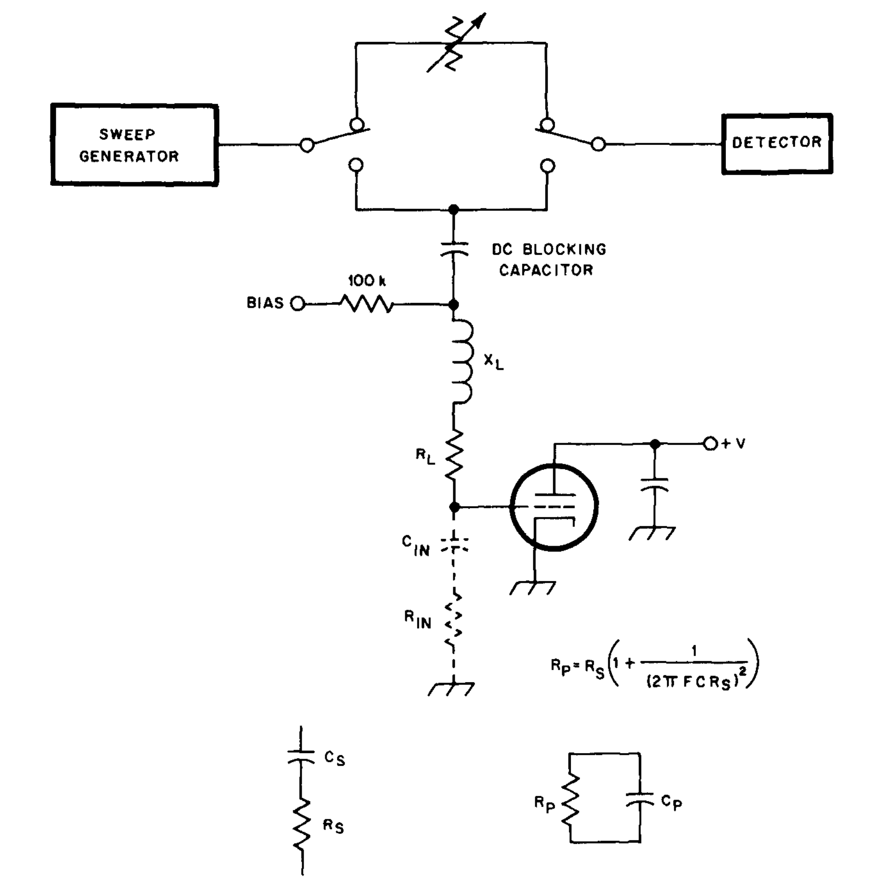


Fig 12—The input impedance of a vacuum tube.

It is commonly stated that the input resistance of a tube is approximately an inverse function of f^2. This statement agrees with the constant resistance described in Table 1 when you remember that the R that is proportional to $1/f^2$ is the equivalent parallel resistance, while that which is approximately constant with frequency is the equivalent series resistance. Calling the former R_p and the latter R_s, it can be easily shown that

$$R_p = R_s\left(1 + \frac{1}{2\pi f R_s C^2}\right) \quad \text{(Eq 1)}$$

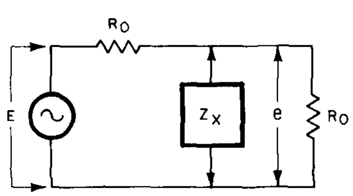
If R_s is assumed constant, and Q is greater than 5, the equation says that R_p is approximately equal to a constant divided by f^2.

Both viewpoints are correct. It seems more convenient, however, to measure and think in terms of the relatively constant series resistive component, rather than the extremely variable parallel one.

Appendix

Appendix 1

(a) The Calculation of Bridging Loss:
Equivalent circuit:



1. for Zx = a pure resistance "Rx"

$$e = E\,\frac{\dfrac{RoRx}{Ro + Rx}}{Ro + \dfrac{RoRx}{Ro + Rx}} = E\,\frac{Rx}{Ro + 2Rx}$$

$$e\ max = \frac{E}{2} \qquad \frac{e\ max}{e} = \frac{E/2}{\dfrac{E\,Rx}{Ro + 2Rx}} = \frac{Ro}{2Rx} + 1$$

insertion loss due to Rx =

$$20 \log_{10} \left| \frac{e\ max}{e} \right| = 20 \log_{10} \left(\frac{Ro}{2Rx} + 1 \right)$$

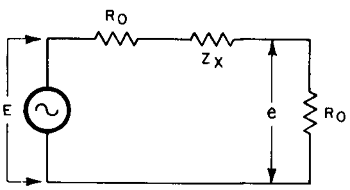
2. for Zx = a pure reactance "*j*x"

$$e = E \frac{\dfrac{jRox}{Ro + jx}}{Ro + \dfrac{jRox}{Ro + jx}} = E \frac{jx}{Ro + 2jx}$$

$$\frac{e\ max}{e} = \frac{E/2}{\dfrac{E\,jx}{Ro + 2jx}} \quad \frac{Ro}{2jx} + 1, \quad \left| \frac{e\ max}{e} \right| = \sqrt{\left(\frac{Ro}{2x} \right)^2 + 1}$$

$$\text{insertion loss due to x} = 20 \log_{10} \sqrt{\left(\frac{Ro}{2x} \right)^2 + 1}$$

(b) The Calculation of Series Loss:
Equivalent circuit:



1. for Zx = a pure resistance "Rx"

$$e = E \frac{Ro}{2Ro + Rx}$$

when Rx = o e max = E/2, $\frac{e\ max}{e} = \frac{\frac{E/2}{E\ Ro}}{2Ro + Rx} = \frac{Rx}{2Ro} + 1$

$$\text{insertion loss due to Rx} = 20 \log_{10} \left| \frac{e\ max}{e} \right| = 20 \log_{10} \left(\frac{Rx}{2Ro} + 1 \right)$$

2. for Zx = a pure reactance "*j*x"

$$e = E \frac{Ro}{2Ro + jx} \qquad \frac{e\ max}{e} = \frac{jx}{2Ro} + 1$$

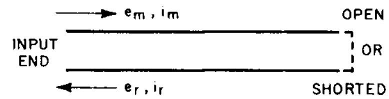
insertion loss due to x =

$$20 \log_{10} \left| \frac{e\ max}{e} \right| = 20 \log_{10} \sqrt{\left(\frac{x}{2Ro} \right)^2 + 1}$$

Appendix 2

The Relation Between Input Resistance and Attenuation for a Resonant Length of Transmission Line

Characteristic impedance of section is Zo



When the far end is open or short-circuited, the reflected voltage or current wave at the input terminals is reduced, compared with the main wave by twice the attenuation of the line expressed in dB (since the reflected wave makes one trip down and one trip back to reach the input terminals). Calling the round trip attenuation "a" (as a current or voltage ratio:

e r = a e m, ir = aim

(a) At a frequency where the input impedance is a maximum

$$R_{IN} = \frac{e\ max}{i\ min} = \frac{em + er}{im - ir} = \frac{em}{im} \left(\frac{1 + a}{1 - a} \right)$$

$$= Zo \left(\frac{1 + a}{1 - a} \right)$$

$$Zo + aZo = R_{IN} - aRin$$

$$\text{So} \quad a = \frac{R_{IN} - Zo}{R_{IN} + Zo}$$

$$\text{the one-way attenuation of this section (dB)} = \frac{20 \log_{10} a}{2}$$

$$= 10 \log_{10} \frac{R_{IN} - Zo}{R_{IN} + Zo}$$

(b) At a frequency where the input impedance is a minimum

$$R_{IN} = \frac{e\ min}{i\ max} = \frac{em - er}{im + ir} = \frac{em}{im} \times \frac{1 - a}{1 + a}$$

$$= Zo \frac{1 - a}{1 + a}$$

$$R_{IN} + aR_{IN} = Zo - aZo, \text{ so } a = \frac{Zo - R_{IN}}{Zo + R_{IN}}$$

the one way attenuation of this section (dB) =

$$10 \log_{10} \frac{Zo - R_{IN}}{Zo + R_{IN}}$$

>50
Focus on technology above 50 MHz

By Bill Olson, W3HQT
Box 1655A, RFD 1
Burnham, ME 04922

RF Power Amplifiers

The last four installments of this column have described the evolution of the modern RF semiconductor with the hope that a little familiarity with the devices will encourage you to build something with one or more of these amazing pieces of modern technology. This month's column will try to impart enough information to get started. As with most things, the best way to learn is by doing; luckily transistors are inexpensive and rugged enough these days that the first time builder can't get into too much trouble! Since most builders will want to start off with an RF power amplifier, I will concentrate on that here and try to show how to select a device and how to get it to work.

Data Sheets

The first thing you need to design an amplifier is a transistor and a manufacturer's data sheet! The transistors are available from a variety of sources including flea markets, manufacturers' sales reps, distributors and just by asking around. The best way to get a package of data sheets is to obtain a transistor data book from the manufacturer. Thomson CSF, Motorola and TRW each publish a book that contains *all* the standard data sheets. These are usually available for free or for a nominal fee from the manufacturer or your local sales representative.

Although most devices are specified for commercial applications such as mobile radio service or for military communications, the ham bands usually come very close to, or fall within, the specified frequency range. This means the manufacturer has already done most, if not all, of the design work. Most data sheets include a recommended circuit, and this is an excellent place to start. For applications in the 50 to 432 MHz range, most commonly available devices are manufactured for the mobile radio service and are characterized as class-C transistors for FM amplifier use. These devices work well as class AB linear amplifiers for reasons outlined later. Okay, what now?

Device Selection

The first consideration in selecting a transistor is frequency. The manufacturers' catalogs generally list devices by frequency range. The mobile radio bands wrap around most of the amateur VHF and UHF bands. Mobile radio devices are characterized at 30 to 88, 136 to 175, 400 to 512 and 800 to 900 MHz. Other popular device groupings include a military communications band at 225 to 400 MHz, several TV translator bands at 175 to 900 MHz, microwave communications bands at 1.4 to 2.7 GHz . . . You get the idea!

Unfortunately there isn't much available in the 1000 to 1400 MHz range because most commercial and military applications here are pulse (radar) type, and the devices (except for low-power stages) do not perform very well in high-duty-cycle modes. Some of the lower power 900-MHz devices will "stretch" up to 1296, however, and there is at least one lineup with moderate power capability specifically built for the amateur 1296-MHz band.

Select a device in the frequency range you want that will handle the power level you need. If there are several choices, price and availability will be considerations. Make sure you have a recommended circuit to work from. If you are building a class-C amplifier within the specified frequency range, just build the manufacturer's circuit! Use good VHF/UHF construction practices (we'll cover these in detail in a later column) and you should have no problems. If you are operating outside the specified band, get as close as you can and expect to tweak the circuit a little. Usually circuits specified for 175 MHz will come very close to tuning at 220 MHz, and so on. If you are building a class-AB linear amplifier, you will need to add components to forward bias the transistor. This is fairly easy as we shall see.

Class C v Class AB

Since most of the readily available devices, at least in the 50 to 432 MHz range, are characterized for class-C FM use, a mobile amplifier for the car FM box can be built right from the manufacturer's data sheet. What about building a linear amplifier for the home station or mobile multimode rig? Fortunately, most modern class-C mobile devices work quite well in class-AB linear service. This is because they are heavily emitter ballasted to make them rugged in an environment where temperatures (in a car trunk) can reach 175°F, line voltage can go to 16 V, and antenna SWR can go to infinity (antenna broken off!).

To forward bias a common-emitter NPN device, you need to apply a positive bias of 0.5-1.0 V to the base. This voltage will turn the device on and cause a quiescent current to flow in the collector of around 1-2% of the maximum rated current. The bias supply should be very "stiff" so that rectified RF voltage in the emitter-base junction will not change the bias point. Normally, bias voltage is obtained through use of a voltage divider off the collector supply. This can be as simple as a 2- to 10-ohm resistor from base to ground and an appropriate dropping resistor from the collector supply to base to cause the desired quiescent current to flow. Quiescent current is usually in the neighborhood of 20 to 150 mA. See Fig 1A.

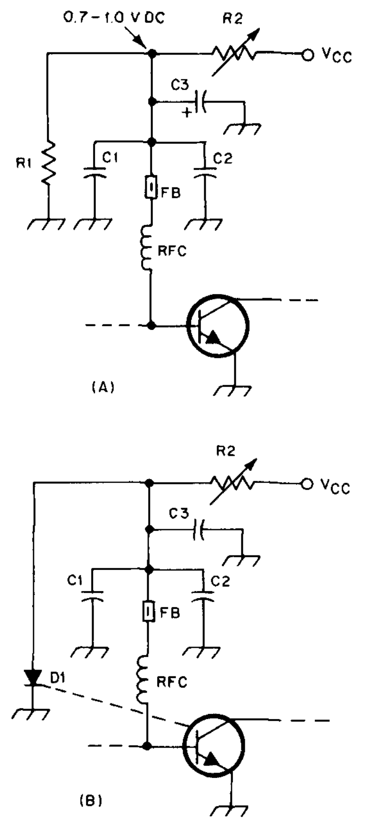


Fig 1—The circuit at A is a class-AB bias circuit using a resistive voltage divider. R1 is 2-10 ohms, depending on power level. R2 will be in the 20-200 ohm range. Make sure that the power rating is adequate. The base choke, RFC, is bypassed at the supply end with the same capacitor values as the collector bypass. Sprinkle ferrite beads liberally. The circuit at B is similar, but it uses a forward-biased diode for some measure of temperature compensation. D1 is coupled thermally to the device case or to the heatsink near the device. A stud-mount diode of the proper polarity works well here.

Better stability of quiescent current with temperature can be obtained by using a forward-biased silicon diode from base to ground. Since the dc current gain of a silicon bipolar tends to increase with temperature, and the forward voltage drop across a silicon diode tends to decrease with temperature, the diode tends to keep the operating point constant with changing temperature. See Fig 1B. In most cases the bias diode is simply placed on the transistor case, sometimes with a little thermal grease. A better method is to use a stud-mount diode of the proper polarity and mount it on the heat sink close to the transistor case.

A word of caution: There are hundreds of different types of silicon power diodes and they all have different V versus I characteristics. It is possible with some diodes to reach the proper bias point with only a small amount of current flowing through the diode—sometimes as low as 20 to 30 mA. In an amplifier requiring a high amount of drive (say more than 4-5 W), rectified RF in the emitter-base junction can cause the bias voltage to rise and change the operating point of the device. If your amplifier seems to saturate early, you may not have a stiff enough bias supply—try a higher current bias diode, two diodes in parallel or a resistor in parallel with the diode and see if this helps.

When using a device specified for class-C service in class-AB linear service, do not expect to see the same output power as shown on the data sheet. Saturated power output in class AB normally runs 60-70% of the class-C value; gain is normally 1-2 dB greater.

Common-Base Devices in Class AB

There is no reason that a common-base device cannot be forward biased. Grounded-grid tube amplifiers work well, and so do their transistor equivalents. The main difference between common-base and common-emitter bias circuits is that the common-base amplifier requires a *negative* bias voltage. Otherwise the rules are pretty much the same. See Fig 2.

Other Considerations

When selecting a device for a particular application, a lot will depend on what is available. The gain of an unmatched transistor will typically fall off by 6 dB each time the frequency is doubled. Internally matched devices essentially use a low-pass LC network on the input and therefore can be used below the recommended frequency range but not much above. For example, internally-matched 450- to 512-MHz mobile devices work very well at 220 MHz, but not at all at 902 MHz.

The newest group of "high gain" VHF mobile devices are actually UHF chips in a VHF package. There are a number of 40-W, 10-dB gain, 2-meter devices on the market that work very well. The biggest drawback in using a device with very high gain is the tendency for the amplifier to be unstable. Designing much more than 10-dB gain in a single class-AB power stage is probably asking for problems.

Most mobile devices are tested at up to 15.5 or 16 V because auto electrical systems can often supply this much voltage. While these devices are specified at 12.5 V, 13.8 to 14.5 V is a safe operating level for these transistors even in class-AB service. The gain and power output will increase as you raise the voltage from here, but the susceptibility to thermal runaway and damage from high SWR will increase. There's no point in sacrificing the reliability of an amplifier for a measly decibel!

Paralleling Devices

While designing and building an amplifier is easiest using a single ended design, there is no reason why devices cannot be paralleled for higher output power. Devices are sometimes combined right at the transistor and rematched from that point out to 50 ohms. Alternatively, two or more complete circuits can be combined either in push-pull or parallel using various combining techniques. I will cover combining techniques in detail in a later column.

Other Device Types

While the most common transistors used for amateur VHF and UHF amplifiers are the mobile radio types, there are many other types that are often available and should not be overlooked. Devices requiring 28-V collector supplies designed for military communications systems are fairly plentiful and usually have higher gain and higher output power per device as compared to their 12.5-V counterparts. For base station use, coming up with the 24 or 28 V is usually not a problem. These devices are normally not as rugged as mobile devices but are certainly usable for our purposes.

Silicon power FETs are just starting to show up as surplus and show great promise for high-power VHF and UHF linear amplifiers. Single-ended 28-V devices will put out over 100 W with 13-dB gain. These devices, while still fairly expensive, are ideal for linear amplifier service because they are easy to bias and do not suffer from thermal runaway problems like bipolar devices do.

Finally, there is a whole range of microwave transistors covering a frequency range from 1 to 4 GHz and higher. While power GaAsFETs haven't shown up on the surplus market yet, there are a lot of useful bipolar devices that have. The standard unmatched 2000 and 3000 series common-base, class-C devices are plentiful and can be used at 1296, 2304 and even 3456 MHz. There are also unmatched linear devices in the 0.5 to 2 W range that make great low level stages or can be combined for higher power. The high power, input- and output-matched devices for the microwave communications bands are a bit more of a problem. Often they are matched with a low-pass network on the input and a shunt inductance (high-pass network) on the output. This makes it hard to use the device outside of its intended frequency range. Unless it was designed for use at amateur frequencies (eg: 2.3 to 2.7 GHz), it is not of much use to us!

While the preceding has not been a "cookbook" construction article, I hope that it has cleared up enough of the unknowns about solid-state amplifier construction that a few brave souls out there will try to do something with those flea market finds. I hope to run a couple of actual construction articles in upcoming *QEX* issues and will certainly try to help anyone that is having problems getting something working.

In upcoming columns I hope to cover a variety of subjects of interest to the VHF/UHF experimenter. Some of the subjects covered will be: microstrip circuitry, test equipment, VHF/UHF components and construction practices, antennas, local oscillators . . . The list gets longer all the time. If any of you have suggestions, send them in! See you next month.

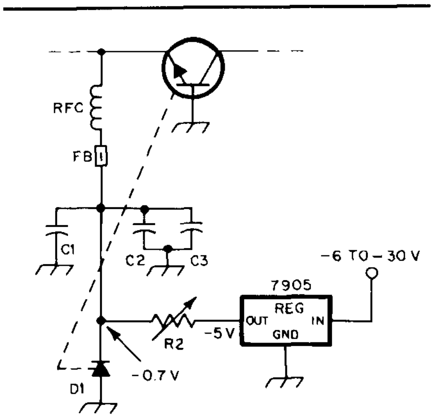


Fig 2—This version of the temperature-compensated bias circuit is for common-base transistors. Note the use of a separate negative bias supply.