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ANNUAL 1986

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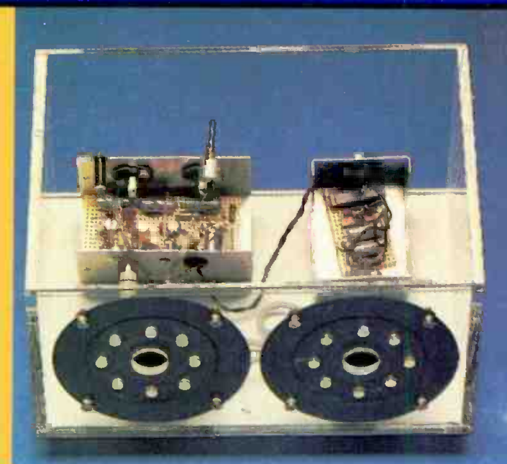

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- Stereo Sound for TV
- Scanner Antenna Plans
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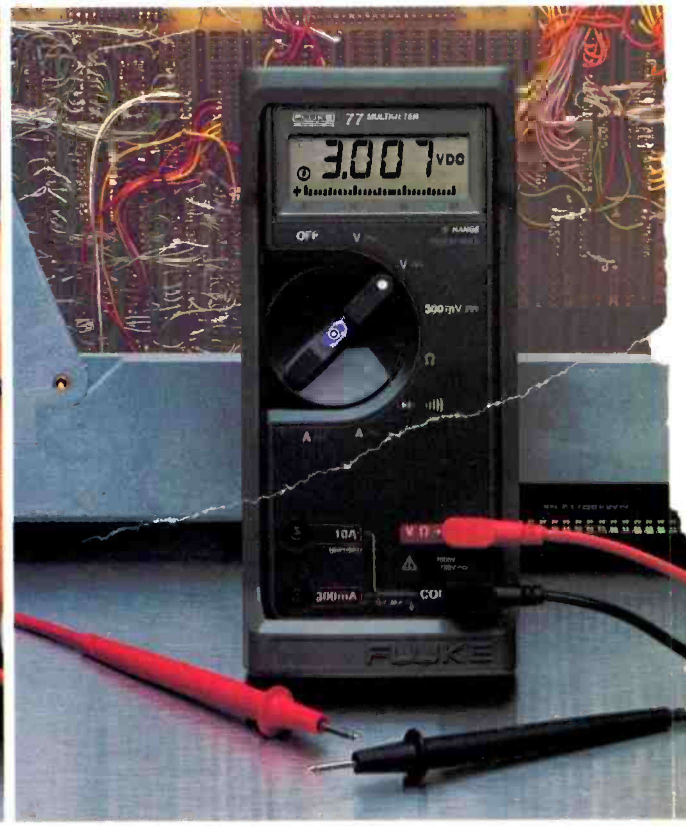

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EDITORIAL

Putting Together the 1986 Edition

Each year I am given the task to assemble the **Radio-Electronics Annual.** Each year I say, "It's a piece of cake!" Each year I am totally amazed at the vast store of quality articles that have appeared in the previous 12 issues of **Radio-Electronics.** And, each year I have to squeeze my final selection of about 250 pages of top-notch articles into 96 pages that are available for me to use.

What to do about it? Get cracking on some basic research! I chatted with the editors and discovered which articles got the biggest play in our reader mail and phone calls. Next, I spoke to our circulation chief who sorted out the compliments from the subscription orders. Of course, my personal selection had something to do with the final selection of articles. It all sounds easy, but the proof in the pudding is the eating. No, don't actually chew the pages of this **Radio-Electronics Annual;** instead, digest the contents by carefully reading those articles that appeal to you. I dare say that the bulk of those supplied will catch your interest. In fact, there's a good possibility you'll be one of those readers who writes to us telling us that you read the **Annual** from cover to cover. If you do, you'll make my day!

I'm a project builder by choice, so you can expect that this issue has a few projects to excite you. You will find a sonic motion detector, and my favorite, the high-power FET audio amplifier. If you are a scanner buff, I have three hot antennas for you to build.

And, I did include exciting features on "What's New in Batteries," "Flat-panel Color TV," "Stereo Sound for TV," and a whole bunch more! Enjoy this issue of **Radio-Electronics Annual 1986.** I did!

Julian S. Martin

Julian S. Martin, KA2GUN
Editor

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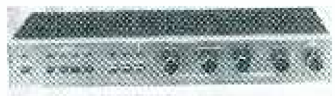
EQUIPMENT REPORTS

Vidicraft Detailer III Image Enhancer

Improve your VCR's performance with this versatile accessory



CIRCLE 225 ON FREE INFORMATION CARD

IT USED TO BE THAT THE WORD "VIDEO" meant nothing more than TV to most people. But, since the advent of VCR, all that has changed. And with those changes has come a change in what we are willing to accept in terms of video quality.

These days, very few are content to "just accept" the video quality provided by our home set-ups. Instead, we are always seeking ways to improve the image that is displayed on our monitors or receivers. One way to achieve a noticeable improvement is with a video amplifier or enhancer. Those units increase picture detail and sharpness by boosting or amplifying the higher frequencies in a video signal. The high frequencies is where much of the fine detail of a video picture is located.

We recently looked at the *Detailer III*—one of the newest video enhancers from Vidicraft (0704 S.W. Bancroft St., Portland, OR 97201).

The *Detailer III*

The *Detailer III* is a video enhancer that is designed to improve the performance of VCR's, video cameras, and videodisc players. As with all other such units, this enhancer's performance is greatly influenced by the quality of the material with which it is used. In other words: The better the source, the better the results. When, for instance, the unit is used to enhance a tape of a quality over-the-air signal, dramatic increases in picture quality wil result. On the other hand, used with a third-generation VHS tape recorded at the machine's slowest speed will produce minimal results.

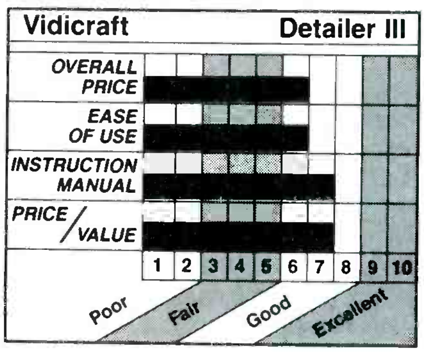
One reason that the law of diminishing returns holds so strongly when it comes to video is that the same high frequencies that hold so much of the picture detail also contain much of the interference that is commonly called snow. Thus, when you enhance detail, you also enhance snow. In order to minimize that increase in snow, most video enhancers are equipped with some sort of noise-reduction system. The one contained in the *Detailer III* is two-fold.

One part of the noise-reduction system in this unit is Vidicraft's *VNX* circuit. That noise-reduction circuit supresses certain low-amplitude, high-frequency enhancements. As such, it seems to perform the exact opposite of the unit's enhancement function. But the *VNX* system uses a different set of thresholds. The result is a reduction of snow at the expense of some of the increased detail, but the overall result is an improved picture.

The second noise-reduction system is "black noise reduction." That system reduces the level of enhancement in the dark areas of the picture. In those areas, increases in detail are not particularly noticeable, but increases in snow are.

One interesting feature of the *Detailer III's* enhancement system is the SPLIT SCREEN function. That allows you to use a front-panel control to split the picture into enhanced and unenhanced regions. That allows you to easily examine the effect of the enhancer on the video signal.

Other features of the unit include a four-input switching system and a distribution amplifier. Both features are capable of handling stereo audio as well as video. The unit's input and output connectors are all located on the rear panel. Included among those are four video inputs, four stereo (or mono) audio inputs, four video



outputs, and four stereo (or mono) audio outputs. Also on the rear panel are three accessory loop input/output connectors. Those allow additional video and audio accessories, such as a video processor or a stereo synthesizer, to be easily interfaced with the system. Any accessory placed in the loop will process any input selected. Input selection is done from the front panel. The selected input is indicated by a front-panel LED.

The *Detailer III* is an extremely versatile device. One indication of that is the number of interconnection schemes presented in the unit's manual. Set-ups with as many as eight permanently connect VCR's are outlined.

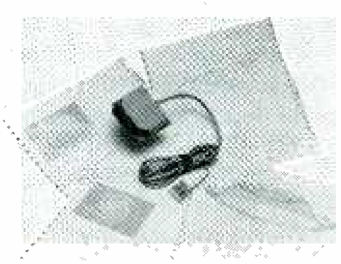
Speaking of the manual, it does an excellent job of showing you how to get the most out of the unit. All of the numerous hook-up schemes are illustrated in painstaking detail, and front-panel settings are both described and shown. Newcomers to video have not been forgotten by the manufacturer; sections covering such basic topics as the differences between the various types of connectors used in video set-ups have been included. Unfortunately, as is the case with many similar pieces of equipment, those more technically inclined have been overlooked; no technical details (theory of operation, schematic, etc) on the unit are provided. Additionally, only rudimentary troubleshooting information is provided.

On the whole, we are very pleased with the *Detailer III*. Its flexibility and performance should put it at the top of any serious video hobbyist's shopping list. The unit, which is covered by a two year warranty, has a suggested retail price of $349.

Cardco Card/? Universal Printer Interface

This interface lets you use almost any printer with your Commodore 64.

CIRCLE 228 ON FREE INFORMATION CARD



BECAUSE OF ITS HIGH PERFORMANCE and low cost, the *Commodore 64* has become one of the most popular computers for home-and-family and school use. Unfortunately, its matching line printer leaves a lot to be desired when it comes to word processing of any kind. In fact, there is no low cost formed-character (daisy-wheel type) or high-quality dot-matrix printer presently available for that computer.

The way to get high quality printouts from the *Commodore 64* (or *VIC-20*) is to use one of the better printers and a *Card/?* interface, a device that lets you use a Centronics-type parallel printer in place of a Commodore printer.

The *Card/?*

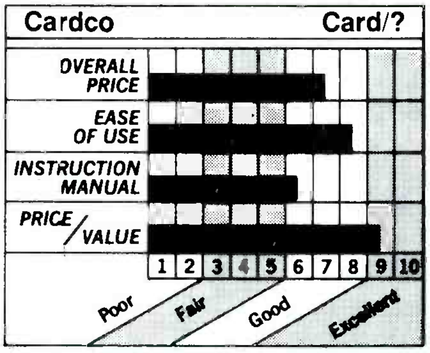
The *Card/?* interface from Cardco, Inc. (313 Mathewson, Wichita, KS 67214) is priced at $69. The unit consists of a small, lightweight plastic box that measures approximately 3⅛ × 3 × ⅞ inches with a Centronics-type connector on one end and a cable on the other end that terminates in a DIN connector that matches the serial output connector on the Commodore computer or its disk drive. (When using a disk drive, the printer connection is moved from the computer to the disk drive.) A single wire trailing from the *Card/?'s* DIN connector is attached to an adapter that slips over the computer's edge connector that provides power and signal I/O for the Commodore *Datassette* (cassette) tape recorder. The wire provides the 5-volt power supply for the interface and still allows the *Datassette* to be used.

The interface plugs directly into the Centronics type connector on the printer. (An earlier version of the *Card/?* interface—called the Model A; the model we are describing is the Model B—was larger and had a ribbon connector between the cabinet and the printer connector.) Its operation is completely automatic. When the computer is told to output to the printer, the interface converts the Commodore's unusual ASCII output to the standard ASCII of the printer. As far as the computer is concerned, it "sees" a simulated Commodore printer.

To avoid problems caused by differences in response to ASCII control codes between the computer and the printer, the interface automatically makes the required conversions. For example, when listing a program, the Commodore's CHR$(19) "home cursor" command would stop an Epson printer dead in its tracks because CHR$(19) is the Epson-printer command for "stop printing." To avoid that hassle, the interface automatically changes the listing from CHR$(19) to an "[HM]" (home cursor). Other ASCII codes from 1 to 31 and 128 to 160, that might be inconsistent with the non-Commodore printer commands, are similarly designated within brackets. For example, CHR$(150), which is the Commodore command for the color "light red," is listed as "[LR]".

The interface normally defaults to the "normal printing mode," which is upper case only with automatic linefeed after carriage return. A short software command can be used to temporarily or "permanently" lock (until power reset) the interface to provide upper case only with no line feed, upper and lower case with no line feed, upper and lower case with automatic linefeed, graphics mode with line feed, or graphics mode with no line feed.

The graphics mode has the ability to pass any character string to the printer unchanged. It's primarily intended for use with word processors and other programs that can function with non-Commodore printers, and that can access the advanced graphics features of certain printers. A semi-permanent selection of the graphics mode can be made by an internal DIP-switch on the printed-circuit board.



Three other DIP switches on the PC board are used to automatically exchange the function of CHR$(15) and CHR$(20); enable or disable software selection of automatic linefeed after carriage return, and enable or disable the ASCII correction described above.

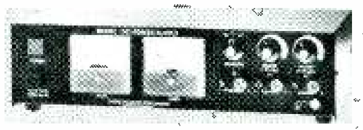
The reason for the automatic exchange of the CHR$(20) and CHR$(15) functions is because Commodore uses CHR$(15) to cancel the expanded print mode, but other printers use CHR$(15) for condensed print with CHR$(20) used to cancel the expanded mode. By automatically swapping CHR$(15) for CHR$(20), the Commodore command to "cancel expanded print mode" will work properly with just about any non-Commodore printer currently on the market.

For listings, user written programs, and word processing, the *Card/?* works as claimed, doing an effective job of emulating a Commodore printer, while providing the enhancements of the higher-performance printers. The few problems that arise, such as dropped spaces between words and stepping of the printer through each blank space (no character) on a line comes about through some off-the-wall programming used in some commercial programs—even some better quality software. Fortunately, programs for the Commodore computers are in BASIC, so it's possible to get into the listings and make whatever changes are necessary to provide rational printer operation.

Overall, the *Card/?* interface is the way to go for "professional quality" printouts from the *Commodore 64* and *VIC-20*.

Global Specialties Model 1301 Power Supply

A DC power supply for both analog and digital applications.



CIRCLE 233 ON FREE INFORMATION CARD

AS ANY ELECTRONICS TECHNICIAN OR hobbyist knows, one of the most important instruments on any workbench is a stable, dependable DC power supply. And that's true whether you work with analog or digital circuitry. But if you work with both, often you will need two such supplies. That's because a supply intended for use with analog circuitry, often is unsuitable for digital circuitry, and vice versa.

One supply that nicely bridges both worlds is the Global Specialties (70 Fulton Terrace, PO Box 1942, New Haven, CT 06509) model *1301* DC power supply. That's because that supply is made up of three independent supplies—a fixed 5-volt supply rated at 1-amp maximum, and two variable 5- to 18-volt supplies rated at 0.5-amp maximum.

The *1301*

The model *1301* power supply can be used in a wide variety of applications. Priced at $219.95, it is equally at home in industry, service shops, schools, or on a hobbyist's workbench.

Housed in a functional, yet attractive, black aluminum case, the unit measures 4 × 14 × 7 inches. It weighs 5 pounds. Power (117-volts AC) is supplied to the unit via a three-wire cord; a 240-volt AC version of the power supply is also available for use abroad.

The three supply outputs are available from the front of the unit via three sets of color-coded binding posts. Those three supplies are isolated, and can be floated to a DC level from any other supply, or from the equipment to which it is connected. In addition, all three supplies can be floated to different levels if desired.

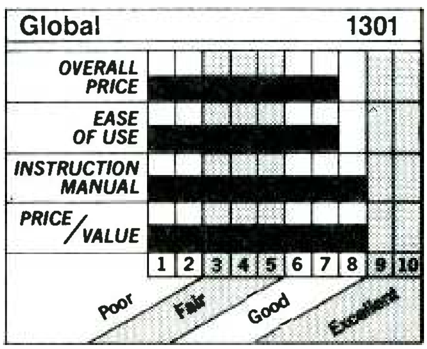
If an earth-ground reference is required for an application any of the six binding-post terminals can be connected to the front-panel "earth-ground reference" binding post. Also, if required, one terminal from one, two, or all three supplies can be simultaneously connected to the earth-ground terminal.

Using the unit

The supplies can be used independently, or can be interconnected to accommodate different voltage and current requirements. For instance, the two variable supplies may be connected in series to provide a variable 10- to 36-volt, 0.5-amp power supply. For a higher voltage, the 5-volt supply can be also combined in series with the two variable supplies, yielding a 15- to 41-volt, 0.5-amp supply. The two variable supplies can also be paralleled, using equalizing resistors, to yield a 5- to 18-volt, 1-amp supply.

Other interconnection schemes are also possible; those are outlined in the unit's instruction manual (more on that later).

Aside from the binding posts,



and the potentiometers used to set the output levels of the variable supplies, the dominant feature of the front panel is the two meters used to monitor the voltage and current outputs of the three supplies. Since only one of the supplies can be monitored at one time, a front-panel MONITOR switch is used to select which of the supplies is monitored.

The *1301* uses current limiting to guard against damage due to short circuits. If the output should be shorted, the voltage drops to zero and the current is limited to about 2.5 amps for the 5-volt supply, and 1 amp for the variable supplies.

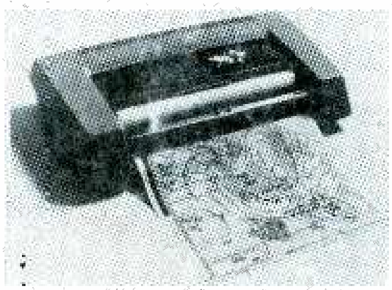
As mentioned previously, the supply is well-regulated. Under a 25%–100% load, the output of the variable supplies is stable to within ±150 mV; the output of the 5-volt supply is stable to ±50 mV. Ripple for the variable supplies is specified as less than 10-mV P-P; for the 5-volt supply it is less than 5-mV P-P.

The documentation that accompanies the unit is brief, but it is well illustrated and does a more than adequate job of describing the unit and how it is used.

Our impressions of the Model *1301* power supply are that it is solidly built and that it performs reliably. The unit is backed by a one-year warranty.

Alden Model 9321 Weatherchart Recorder

Keep an eye on the weather with this chart recorder. It's available in kit form, too.



CIRCLE 237 ON FREE INFORMATION CARD

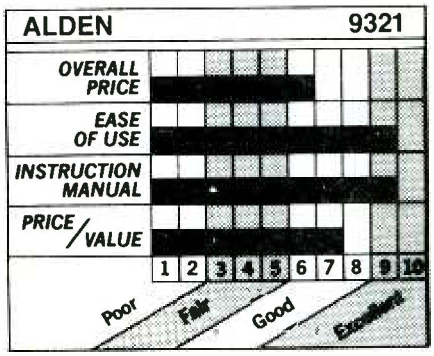
DOES YOUR MIND COME TO ATTENTION when you hear weather reports of storms brewing at sea? If you are an avid sailor, or you're just into weather forecasting as a hobby, you need to know all there is to know about what's happening "out there."

One way to keep track of the ocean's surface weather, ice formations, the condition of the Gulf Stream, or anything else having to do with the "big ponds," is through the Alden model *9321* Weatherchart Recorder (Alden Electronics, Washington St., Westborough, MA 01581.)

The Alden Weatherchart Recorder is a facsimile printer specifically designed to recreate the charts broadcast on shortwave frequencies by marine radiofacsimile stations throughout the world. The North and South Atlantic and Pacific oceans, the Indian ocean, the Antarctic, the Red Sea, the Persian Gulf, and coastal waters are all served by the radiofacsimile broadcasts.

The charts are broadcast on many different frequencies, from 4 MHz to approximately 20 MHz. (A directory of the stations, frequencies, and time of operation is supplied with the recorder.) The facsimile signals, which are easily recognized by their distinctive ding-dong sound, can be received on any shortwave receiver capable of upper-sideband reception. The tones are converted to hard-copy printouts by the Alden Weatherchart Recorder.

The chart recorder is housed in a plastic cabinet that measures 17 1/16 × 3 5/8 × 10 1/4 inches. It weighs a shade over 10 pounds. It is powered by 117-volts AC. The input to the recorder is 600 ohms balanced, available at a terminal strip located on the rear. An accessory matching transformer is provided for unbalanced receiver outputs, such as a headphone jack. However, we connected the recorder's 600-ohm input directly to a receiver's 4-ohm headphone output and had no difficulty of any kind in driving the recorder. It is possible that some receivers might require the matching transformer, but we tried several, ranging from



a budget-priced "shortwave radio" to a top-of-the-line communications receiver, and always got good results without the matching transformer.

The top of the recorder has the main power switch, the start switch, two LED's that serve as tuning indicators, and a framing switch that centers the pictures on the paper.

The charts are created on a roll of 11-inch wide electrosensitive paper that is supplied in a cylindrical cassette that mounts near the front of the machine. (You tear off the charts as needed.) Motor-driven rollers located in front of the cassette feed the paper out. The image is traced on the paper by a stylus assembly located between the cassette and the rollers that "burns" the image into the paper. As you would expect from the method of creating the image, the paper is damp because it contains a conductive fluid. The electric current representing the image passes through the paper and the stylus, causing a burn where they touch.

The recorder responds to FSK (*F*requency *S*hift *K*eying) frequencies of 1500 Hz ("white") and 2300 Hz ("black"). While the machine can be started and stopped manually, it also operates under tone control, broadcast from the radio-facsimile stations.

How it works

The receiver is first pretuned to the desired station by adjusting the receiver's tuning control until the "white" tuning indicator flickers most of the time and the "black" indicator flickers occasionally. The actual tuning adjustment isn't critical; as long as the tuning indicator lights appear to

(continued on page 91)

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SN74365N	16	.55
SN74366N	16	.55
SN74367N	16	.55
SN74368N	16	.55
SN74390N	16	1.49
SN74393N	14	1.49

74LS

Part No.	Pins	Price
74LS00	14	.29
74LS01	14	.29
74LS02	14	.35
74LS03	14	.29
74LS04	14	.39
74LS05	14	.39
74LS06	14	.99
74LS07	14	.99
74LS08	14	.35
74LS09	14	.35
74LS10	14	.35
74LS11	14	.35
74LS14	14	.59
74LS20	14	.29
74LS21	14	.35
74LS26	14	.35
74LS27	14	.35
74LS28	14	.39
74LS30	14	.39
74LS32	14	.39
74LS37	14	.39
74LS38	14	.39
74LS42	16	.49
74LS47	16	.89
74LS51	14	.29
74LS73	14	.39
74LS74	14	.49
74LS75	16	.45
74LS76	16	.39
74LS85	16	.89
74LS86	14	.39
74LS90	14	.55
74LS92	14	.55
74LS93	14	.55
74LS96	16	.89
74LS107	14	.45
74LS109	16	.39
74LS112	16	.39
74LS122	14	.49
74LS123	16	.79
74LS125	14	.59
74LS126	14	.59
74LS132	14	.65
74LS133	16	.59
74LS136	14	.39
74LS138	16	.59
74LS139	16	.59
74LS145	16	1.19
74LS147	16	1.95
74LS148	16	1.79
74LS151	16	.59
74LS153	16	.59
74LS154	24	1.49
74LS155	16	.69
74LS156	16	.69
74LS157	16	.69
74LS158	16	.59
74LS160	16	.69
74LS161	16	.69
74LS162	16	.69
74LS163	16	.69
74LS164	14	.89
74LS165	16	.89
74LS168	16	1.19
74LS169	16	1.49
74LS170	16	1.49
74LS173	16	.69
74LS174	16	.69
74LS175	16	.69
74LS181	24	2.49
74LS190	16	.79
74LS191	16	.89
74LS192	16	.79
74LS193	16	.79
74LS194	16	.69
74LS195	16	.69
74LS196	14	.89
74LS197	14	.89
74LS221	16	1.09
74LS240	20	1.09
74LS241	20	.99
74LS243	14	.99
74LS244	20	1.29
74LS245	20	1.49
74LS251	16	.59
74LS253	16	.59
74LS257	16	.59
74LS258	16	.59
74LS259	16	1.49
74LS260	14	.59
74LS266	14	.55
74LS273	20	1.49
74LS279	16	.49
74LS280	14	1.95
74LS299	20	2.95
74LS322	20	3.95
74LS323	20	3.95
74LS347	16	1.95
74LS353	16	1.29
74LS364	20	1.95
74LS365	16	.49
74LS366	16	.49
74LS367	16	.49
74LS368	16	.49
74LS373	20	1.49
74LS374	20	1.49
74LS375	16	.69
74LS386	14	.39
74LS393	14	1.19
74LS490	16	1.95
74LS533	20	1.95
74LS534	20	1.95
74LS540	20	1.49
74LS541	20	1.49
74LS640	20	2.19
74LS641	20	2.19
74LS644	20	2.19
74LS645	20	2.19
74LS670	16	1.49
74LS688	20	2.95
81LS95	20	1.49
81LS96	20	1.49
81LS97	20	1.49
81LS98	20	1.49

74S/PROMS*

Part No.	Pins	Price
74S00	14	.35
74S02	14	.35
74S04	14	.45
74S05	14	.45
74S08	14	.45
74S09	14	.39
74S10	14	.35
74S11	14	.35
74S15	14	.35
74S20	14	.35
74S22	14	.35
74S30	14	.35
74S32	14	.45
74S37	14	.99
74S38	14	.99
74S64	14	.39
74S65	14	.39
74S74	14	.55
74S85	16	1.99
74S86	14	.55
74S112	16	.55
74S124	16	2.75
74S132	14	1.89
74S133	16	.45
74S135	16	.89
74S136	14	1.39
74S138	16	.89
74S139	16	.89
74S140	14	.69
74S151	16	.99
74S153	16	.99
74S157	16	.99
74S158	16	.95
74S160	16	2.29
74S169	16	4.29
74S174	16	1.09
74S175	16	1.09
74S188*	16	1.75
74S194	16	1.49
74S195	16	1.49
74S196	14	1.49
74S240	20	1.95
74S241	20	1.95
74S242	14	1.95
74S244	20	2.19
74S251	16	.95
74S253	16	.99
74S257	16	.99
74S258	16	.99
74S273	20	2.39
74S280	14	1.89
74S287*	16	1.79
74S288*	16	1.79
74S299	20	5.95
74S373	20	2.49
74S374	20	2.49
74S387*	16	1.95
74S471*	20	4.95
74S472*	20	4.95
74S473*	20	4.95
74S570*	16	2.95
74S571*	16	2.95
74S572*	18	4.95
74S573*	18	4.95

74ALS

Part No.	Pins	Price
74ALS00	14	.59
74ALS02	14	.59
74ALS04	14	.59
74ALS08	14	.59
74ALS10	14	.59
74ALS30	14	.59
74ALS32	14	.65
74ALS74	14	.79
74ALS109	16	.79
74ALS112	16	.79
74ALS138	16	1.25
74ALS240	20	2.25
74ALS244	20	2.25
74ALS245	20	2.59
74ALS373	20	2.59
74ALS374	20	2.59

74F

Part No.	Pins	Price
74F00	14	.69
74F02	14	.75
74F04	14	.89
74F08	14	.75
74F10	14	.75
74F20	14	.75
74F32	14	.79
74F74	14	.85
74F86	14	1.15
74F109	16	.95
74F138	16	1.69
74F139	16	1.69
74F157	16	1.69
74F158	16	1.69
74F240	20	3.75
74F244	20	3.49
74F253	16	1.75
74F257	16	1.79
74F280	14	1.69
74F373	20	4.89
74F374	20	4.59
74F379	16	1.99

CD—CMOS

Part No.	Pins	Price
CD4000	14	.29
CD4001	14	.29
CD4002	14	.29
CD4006	14	.89
CD4007	14	.29
CD4008	16	.89
CD4009	16	.49
CD4010	16	.49
CD4011	14	.29
CD4012	14	.29
CD4013	14	.39
CD4014	16	.89
CD4015	16	.39
CD4016	14	.39
CD4017	16	.69
CD4018	16	.79
CD4019	16	.49
CD4020	16	.75
CD4021	16	.75
CD4022	16	.75
CD4023	14	.29
CD4024	14	.69
CD4025	14	.29
CD4026	16	1.59
CD4027	16	.45
CD4028	16	.69
CD4029	16	.79
CD4030	14	.39
CD4034	24	1.79
CD4035	16	.79
CD4040	16	.75
CD4041	14	.75
CD4042	16	.69
CD4043	16	.79
CD4044	16	.79
CD4046	16	.85
CD4047	14	.89
CD4049	16	.39
CD4050	16	.39
CD4051	16	.79
CD4052	16	.79
CD4053	16	.79
CD4056	16	2.95
CD4059	24	3.95
CD4060	16	.89
CD4066	14	.39
CD4068	14	.39
CD4069	14	.29
CD4070	14	.35
CD4071	14	.29
CD4072	14	.29
CD4073	14	.29
CD4075	14	.29
CD4076	16	.89
CD4077	14	.35
CD4078	14	.29
CD4081	14	.29
CD4082	14	.29
CD4093	14	.49
CD4094	16	1.95
CD4098	16	1.95
CD4099	16	1.89
CD4503	16	.69
CD4508	24	1.95
CD4510	16	.85
CD4511	16	.85
CD4512	16	.85
CD4514	24	1.49
CD4515	24	1.79
CD4516	16	1.59
CD4518	16	.89
CD4519	16	.39
CD4520	16	.79
CD4522	16	1.19
CD4526	16	.89
CD4528	16	1.19
CD4529	16	1.19
CD4531	16	.89
CD4538	16	1.69
CD4541	14	1.49
CD4543	16	1.19
CD4553	16	4.95
CD4566	16	2.95
CD4583	16	2.49
CD4584	14	.59
CD4585	16	1.39
CD4723	16	1.19
CD4724	16	1.19
MC14410	16	8.95
MC14411	24	11.95
MC14412	16	9.95
MC14433	24	17.95
MC14490P	16	4.95
MC14572	16	1.19

RED-HOT RAM & EPROM PRICES

Part No.	Description	Price
21C14	(200ns) CMOS SRAM — CMOS USES LESS POWER	.99
27C16	(450ns) CMOS EPROM	9.95
4164N-200	(DRAM)	9/9.95
6116P-4	(200ns) SRAM	3.49
6116LP-4	(200ns) L.P. SRAM	3.69
6264LP-15	(150ns) L.P. SRAM	7.49
MC146818	REAL TIME CLOCK & RAM	7.95
27128-25	(250ns) EPROM	5.95
41256-150	(150ns) DRAM	6.49
68764	(450ns) 21V EPROM	12.95
68766	(350ns) 25V EPROM	14.95

MICROPROCESSOR COMPONENTS

MICROPROCESSOR CHIPS

Part No.	Pins	Function	Price
D765AC	40	Floppy Disk Controller	16.95
D3242	28	Addr. Multiplexer & Refresh Counter	7.95
TMS5501	40	Synchronous Data Interface (SIRC)	14.95
Z80, Z80A, Z80B, Z8000 SERIES			
Z80	40	CPU (MK3880N) (Z80C) 2.5MHz	2.75
Z80 CTC	28	Counter Timer Circuit	3.49
Z80 DART	40	Dual Asynchronous Rec./Trans.	8.95
Z80-DMA	40	Direct Memory Access Circuit	12.49
Z80 P10	40	Parallel I/O Interface Controller	2.95
Z80 S10/0	40	Serial I/O (TxCB and RxCB Bonded)	11.49
Z80 S10/1	40	Serial I/O (Lacks DTRB)	11.49
Z80 S10/2	40	Serial I/O (Lacks SYNCB)	11.49
Z80 S10/9	40	Serial I/O	11.49
Z80A	40	CPU (MK3880N-4) (780C-1) 4MHz	2.95
Z80A CTC	28	Counter Timer Circuit	3.95
Z80A DART	40	Dual Asynchronous Rec./Trans.	9.95
Z80A-DMA	40	Direct Memory Access Circuit	12.95
Z80A-P10	40	Parallel I/O Interface Controller	3.95
Z80A S10/0	40	Serial I/O (TxCB and RxCB Bonded)	11.95
Z80A-S10/1	40	Serial I/O (Lacks DTRB)	11.95
Z80A-S10/2	40	Serial I/O (Lacks SYNCB)	11.95
Z80A-S10/9	40	Serial I/O	11.95
Z80B	40	CPU (MK3880N-6) 6MHz	8.95
Z80B CTC	28	Counter Timer Circuit	11.95
Z80B DART	40	Dual Asynchronous Rec./Trans.	19.95
Z80B-P10	40	Parallel I/O Interface Controller	10.95
6500/6800/68000 SERIES			
6502	40	MPU with Clock (1MHz)	4.95
6502A	40	MPU with Clock (2MHz)	5.25
6502B	40	MPU with Clock (3MHz)	7.95
6520	40	Peripheral Inter. Adapter	2.75
6522	40	Versatile Inter. Adapter	4.95
6551	28	Async. Comm. Interface Adapt.	6.95
6800	40	MPU	2.95
6802	40	MPU with Clock and RAM	5.95
6809	40	CPU — 8 Bit (On-Chip Oscillator)	6.95
6809E	40	CPU — 8 Bit (External Clocking)	8.49
68B09E	40	CPU — 8 Bit (Ext. Clocking) 2MHz	11.49
6810	24	128x8 Static RAM	2.75
68B10	24	128x8 Static RAM (2MHz)	5.95
6821	40	Peripheral Inter Adapt (MC6820)	2.75
68B21	40	Peripheral Interface Adapter (2MHz)	4.95
6845	40	CRT Controller (CRTC)	9.95
68B45	40	CRT Controller (CRTC) 2MHz	14.95
6850	24	Asynchronous Comm. Adapter	2.95
6860	24	0-600bps Digital MODEM	6.95
68000L8	64	MPU 16-Bit (8MHz)	19.95
68488P	40	General Purpose Int. Adapter	9.95
68661	28	Enhanced Prog. Comm. Interface (2661)	8.95
8000/80000 SERIES			
8031	40	Control Oriented CPU w/RAM & I/O	12.95
8035	40	MPU — 8-Bit	4.95
8039	40	CPU — Sgl. Chip 8-Bit (128bts. RAM)	4.95
8060	40	CPU — 8-Bit NMOS	12.95
8073N	40	CPU w/Basic Micro Interpreter	29.95
8080A	40	CPU	3.95
8085A	40	CPU	3.95
8085A-2	40	CPU-8 Bit N-Channel (5MHz)	10.95
8086-2	40	CPU 16-bit 8MHz	19.95
8087	40	Arithmetic Processor (5MHz)	119.00
8087-2	40	Arithmetic Processor (8MHz)	125.00
8088	40	CPU 8/16-Bit	14.95
8116	18	Dual Baud Rate Generator	9.49
8155	40	HMOS RAM I/O Port-Timer	4.95
8156	40	RAM with I/O Port and Timer	5.95
8202	40	Dynamic RAM Controller	19.95
8203	40	64K Dynamic RAM Controller	29.95
8205	16	Hi Speed 1 out of 8 Binary Decoder	3.95
8212	24	8-Bit Input/Output (74S412)	2.25
8224	16	Clock Generator Driver	2.19
8228	28	Sys. Cont./Bus Driver (74S428)	3.95
8237-5	40	High Perf. Prog. DMA Cont. (5MHz)	12.95
8238	28	System Controller (74S438)	4.95
8243	24	I/O Expander for 48 Series	3.95
8250A	40	Async. Comm. Element	9.95
8250B	40	ACE (IBM PC or XT Software Compatible)	10.95
8251	28	Prog. Comm. I/O (USART)	3.25
8251A	28	Prog. Comm. Interface (USART)	3.49
8253-5	24	Prog. Interval Timer	6.49
8254	24	Programmable Interval Timer	13.49
8255	40	Prog. Peripheral I/O (PPI)	3.95
8255A-5	40	Prog. Peripheral I/O (PPI) 5MHz	4.25
8257-5	40	Prog. DMA Controller	6.95
8259	28	Prog. Interrupt Control	5.95
8259-5	28	Prog. Interrupt Controller	6.95
8272	40	Sgle/Dble Density Floppy Disk Cont.	16.95
8274	40	Multi-Protocol Serial Cont. (7201)	14.95
8275	40	Prog. CRT Controller	14.95
8279	40	Prog. Keyboard/Display Interface	5.49
8279-5	40	Prog. Keyboard/Display Interface	5.95
8282	20	Octal Latch	6.49
8284	18	Clock Generator/Driver	5.49
8286	20	Octal Bus Transceiver	6.49
8287	20	Octal Bus Transceiver (Inverted)	6.49
8288	20	Bus Controller	13.95
8289	20	Bus Arbiter	24.95
8741	40	8 Bit Univ. Peripheral Interface	19.95
8748	40	HMOS EPROM MPU	19.95
8749	40	MPU 8-Bit EPROM Version of 8049)	19.95
8751	40	CPU w/4Kx8 EPROM & 128x8 RAM	29.95
8755	40	16K EPROM with I/O	19.95
80186	68	High Integration 16 Bit MPU	19.95
80188	68	High Integra. 16-Bit MPU (8-Bit Data Bus)	19.95
80287	40	Numeric Processor Ext.	195.00
SPECIAL FUNCTION			
MC3470P	18	Floppy Disk Read Amp System	4.95
MM5321N	16	TV Camera Sync. Generator	9.95
MM58167AN	24	Microprocessor Real Time Clock	8.95
MM58174AN	16	Micro. Compatible Time Clock	8.95
MM5369AA/N	8	Prog. Oscillator/Divider (60Hz)	1.79
MM5369EST	8	Prog. Oscillator/Divider (100Hz)	1.95
MC146818	24	Real Time Clock Plus RAM	7.95

DYNAMIC RAMS

Part No.	Pins	Function		Price
1103	18	1024x1	(300ns)	.99
4027	16	4096x1	(250ns)	1.49
4116N-15	16	16,384x1	(150ns)	1.39 — 8/10.95
4116N-20	16	16,384x1	(200ns)	.79 — 8/5.29
4116N-25	16	16,384x1	(250ns)	.69 — 8/5.49
4164N-150	16	65,536x1	(150ns)	1.22 — 9/10.95
4164N-200	16	65,536x1	(200ns)	1.11 — 9/9.95
MM5261	18	1024x1	(300ns)	35 — 8/1.95
MM5262	22	2048x1	(365ns)	35 — 8/1.95
MM5270	18	4096x1	(250ns)	4.95
MM5280	22	4096x1	(300ns) 2107	3.95
MM5298-3	16	8192x1	(250ns)	.59
8118	16	16,384x1	(120ns) • 5V Only Req.	.99
41256-150	16	262,144x1	(150ns)	6.49
41256-200	16	262,144x1	(200ns)	5.95
4128	16	131,072x1	(250ns)	8.95

STATIC RAMS

Part No.	Pins	Function		Price
2101	22	256x4	(450ns) 8101	1.95
2102	16	1024x1	(350ns)	.89
2102-2L	16	1024x1	(250ns) L.P. (91L02)	1.49
2111	18	256x4	(450ns) 8111	2.49
2112	16	256x4	(450ns) MOS	2.49
2114N	18	1024x4	(450ns)	1.29 — 8/9.95
2114N-L	18	1024x4	(450ns) L.P.	1.65 — 8/12.95
2114N-2	18	1024x4	(200ns)	1.39 — 8/10.95
2114N-2L	18	1024x4	(200ns) L.P.	1.69 — 8/13.49
2147HN	18	4096x1	(70ns)	4.49
2148HN	18	1024x4	(70ns)	4.95
TMS4045	18	1024x4	(450ns)	3.95
TMS40L47-45	20	1024x4	(450ns)	1.95
5101	22	256x4	(450ns) CMOS	2.95
MM5257	18	4096x1	(450ns) 4044	4.95
HM6116P-2	24	2048x8	(120ns) CMOS	4.95
HM6116LP-2	24	2048x8	(120ns) L.P. CMOS	6.49
HM6116P-3	24	2048x8	(150ns) CMOS	3.75
HM6116LP-3	24	2048x8	(150ns) L.P. CMOS	3.95
HM6116P-4	24	2048x8	(200ns) CMOS	3.49
HM6116LP-4	24	2048x8	(200ns) L.P. CMOS	3.69
HM6264P-12	28	8192x8	(120ns) CMOS	7.25
HM6264LP-12	28	8192x8	(120ns) L.P. CMOS	7.95
HM6264P-15	28	8192x8	(150ns) CMOS	6.95
HM6264LP-15	28	8192x8	(150ns) L.P. CMOS	7.49
27LS00	16	256x1	(80ns) L.P.	3.95
7489	16	16x4	(50ns) 3101	2.25
74C921	18	256x4	(250ns) CMOS	5.95
74C930	18	1024x1	(250ns) CMOS (6518)	5.95
74S189	16	16x4	(35ns) 93405	2.95
74S289	16	16x4	(35ns) 3101	2.95
82S10	16	1024x1	(50ns) O.C. (93415)	3.95
82S25	16	16x4	(50ns) O.C. (74S289)	2.25

PROMS/EPROMS

Part No.	Pins	Function		Price
1702A	24	256x8	(1µs)	3.95
TMS2516	24	2048x8	(450ns)	4.95
TMS2532	24	4096x8	(450ns)	5.49
TMS2564	28	8192x8	(450ns)	10.95
2708	24	1024x8	(450ns)	3.95
TMS2716	24	2048x8	(450ns) 3 voltage	7.95
2716	24	2048x8	(450ns)	3.95
27C16	24	2048x8	CMOS	9.95
2716-1	24	2048x8	(350ns)	4.95
27160-5	24	2048x8	(550ns)	3.75
2732	24	4096x8	(450ns)	4.25
2732A-20	24	4096x8	(200ns) 21V	9.95
2732A-25	24	4096x8	(250ns) 21V	5.95
2732A-45	24	4096x8	(450ns) 21V	4.49
27C32	24	4096x8	CMOS	11.95
27C32A-30	24	4096x8	(300ns) 21V (CMOS)	22.95
2764-20	28	8192x8	(200ns) 21V	6.95
2764-25	28	8192x8	(250ns) 21V	5.09
2764A-25	28	8192x8	(250ns) 12.5V	5.95
2764-45	28	8192x8	(450ns) 21V	4.95
27C64	28	8192x8	CMOS 21V	11.95
27128-25	28	16,384x8	(250ns) 128K 21V	5.95
27128A-25	28	16,384x8	(250ns) 128K 12.5V	7.95
27256-25	28	32,768x8	(250ns) 256K (14V)	11.95
68764	24	8192x8	(450ns) 21V	12.95
68766	24	8192x8	(350ns) 25V	14.95
74S188	16	32x8	PROM O.C. (6330-1)	1.75
74S287	16	256x4	PROM T.S. (6301-1)	1.79
74S288	16	32x8	PROM T.S. (6331-1)	1.79
74S387	16	256x4	PROM O.C. (6300-1)	1.95
74S471	20	256x8	PROM T.S. (6309-1)	4.95
74S472	20	512x8	PROM T.S. (6349-1)	4.95
74S473	20	512x8	PROM O.C. (6348)	4.95
74S474	24	512x8	PROM T.S. (DM87S296N)	4.95
74S475	24	512x8	PROM O.C. (6340)	4.95
74S476	18	1024x4	PROM T.S.	6.95
74S478	24	1024x8	PROM T.S.	9.95
74S570	16	512x4	PROM O.C. (6305)	2.95
74S571	16	512x4	PROM T.S. (6306)	2.95
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82S123	16	32x8	PROM T.S. (27S19)	2.95
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82S129	16	256x4	PROM T.S. (27S21)	2.95
82S130	16	512x4	PROM O.C. (27S12)	3.95
82S185	18	2048x4	PROM T.S. (TBP24S81)	9.95
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DM87S181N	24	1024x8	PROM T.S. (82S181)	9.95

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ADC0801	20	8-Bit A/D Converter (1/4LSB)	14.95
ADC0803	20	8-Bit A/D Converter (1/2LSB)	4.95
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ADC0808	28	8-Bit A/D Conv. w/8-Channel Analog	9.95
ADC0809	28	8-Bit A/D Converter (8 Ch. Multi.)	4.49
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DAC0806	16	8-Bit D/A Converter (0.78% Lin.)	1.95
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14 pin LP	17	15	14
16 pin LP	19	17	16
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20 pin LP	30	27	25
22 pin LP	30	27	25
24 pin LP	33	30	28
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40 pin LP	49	45	43

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16 pin SG	55	49	45
18 pin SG	65	59	51
20 pin SG	79	69	59
22 pin SG	79	69	65
24 pin SG	79	69	65
28 pin SG	95	85	79
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14 pin WW	75	69	65
16 pin WW	79	72	65
18 pin WW	95	85	75
20 pin WW	1.19	1.09	95
22 pin WW	1.29	1.19	1.05
24 pin WW	1.35	1.19	1.05
28 pin WW	1.69	1.55	1.39
36 pin WW	1.89	1.79	1.59
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7216DIPI	28	8 Digit Freq. Counter C.C.	21.49
7217IJI	28	4 Digit LED Up Down Counter C.A.	10.95
7217AIPI	28	4 Digit LED Up Down Counter C.C.	9.95
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7226AEV Kit	40	5 Function Counter Chip, XTL (Evaluation Kit)	99.95

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74HC02	14	.59
74HC03	14	.89
74HC04	14	.59
74HCU04	14	.69
74HC08	14	.59
74HC10	14	.59
74HC11	14	.69
74HC14	14	.89
74HC20	14	.59
74HC27	14	.59
74HC30	14	.69
74HC32	14	.79
74HC42	16	1.09
74HC51	14	.89
74HC58	14	.89
74HC73	14	.79
74HC74	14	.79
74HC75	16	.99
74HC76	16	.79
74HC85	16	1.69
74HC86	14	.75
74HC107	14	.79
74HC109	16	.79
74HC112	16	.79
74HC123	16	2.29
74HC125	14	1.75
74HC132	14	1.29
74HC137	16	1.59
74HC138	16	1.19
74HC139	16	1.05
74HC147	16	1.29
74HC151	16	.99
74HC153	16	1.09
74HC154	24	2.65
74HC157	16	.99
74HC158	16	.99
74HC160	16	1.39
74HC161	16	1.39
74HC162	16	1.39
74HC163	16	1.39
74HC164	14	1.35
74HC165	16	2.15
74HC166	16	2.49
74HC173	16	1.29
74HC174	16	1.09
74HC175	16	1.09
74HC190	16	1.59
74HC191	16	1.59
74HC192	16	1.49
74HC193	16	1.49
74HC194	16	1.19
74HC195	16	1.19
74HC221	16	2.95
74HC237	16	1.49
74HC240	20	2.29
74HC241	20	2.29
74HC242	14	2.15
74HC243	14	2.15
74HC244	20	2.29
74HC245	20	2.59
74HC251	16	.99
74HC253	16	1.09
74HC257	16	.99
74HC259	16	1.69
74HC266	14	.89
74HC273	20	2.79
74HC280	14	4.59
74HC299	20	5.59
74HC366	16	2.59
74HC367	16	2.59
74HC373	20	2.69
74HC374	20	2.69
74HC390	16	1.59
74HC393	14	1.59
74HC533	20	2.69
74HC534	20	2.69
74HC595	16	3.19
74HC688	20	3.59
74HC4024	14	1.75
74HC4040	16	1.49
74HC4049	16	.89
74HC4050	16	.89
74HC4060	16	1.49
74HC4075	14	.59
74HC4078	14	.59
74HC4511	16	1.95
74HC4514	24	4.19
74HC4538	16	2.59
74HC4543	16	3.75

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74C00	14	.29
74C02	14	.35
74C04	14	.35
74C08	14	.35
74C10	14	.35
74C14	14	.59
74C20	14	.35
74C30	14	.35
74C32	14	.39
74C42	16	1.19
74C48	16	1.79
74C73	14	.69
74C74	14	.59
74C85	16	1.39
74C86	14	.29
74C89	16	5.95
74C90	14	1.09
74C93	14	1.09
74C95	14	1.19
74C107	14	.79
74C151	16	2.19
74C154	24	3.25
74C157	16	1.75
74C160	16	1.19
74C161	16	1.19
74C162	16	1.19
74C163	16	1.19
74C164	14	1.29
74C165	16	1.29
74C173	16	.89
74C174	16	1.19
74C175	16	1.19
74C192	16	1.39
74C193	16	1.39
74C195	16	1.29
74C221	16	1.75
74C240	20	1.95
74C244	20	1.95
74C373	20	2.29
74C374	20	2.29
74C901	14	.59
74C902	14	.79
74C903	14	.59
74C906	14	.59
74C907	14	.89
74C911	28	8.95
74C912	28	8.95
74C915	18	1.19
74C917	28	8.95
74C922	18	4.49
74C923	20	4.95
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80C97	16	.69

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TL072CP	8	1.09
TL074CN	14	1.95
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TL082CP	8	1.19
TL084CN	14	1.95
LM109K		5.95
LM301CN	8	.39
LM302H		2.49
LM304H		1.95
LM305H		.99
LM307CN	8	.49
LM308CN	8	.69
LM309K		1.25
LM310CN	8	1.95
LM311CN	8	.59
LM312H		2.79
LM317T		1.19
LM317K		3.49
LM318CN	8	1.59
LM319N	14	1.49
LM320K-5		1.35
LM320K-12		1.35
LM320K-15		1.35
LM320K-24		1.35
LM320T-5		.85
LM320T-12		.85
LM320T-15		.85
LM320T-24		.85
LM322N	14	1.49
LM323K		4.95
LM324N	14	.59
LM329DZ		.65
LM331N	8	3.95
LM334Z		1.19
LM335Z		1.29
LM336Z		1.09
LM337MP		1.15
LM337T		1.89
LM338K		6.95
LM339N	14	.69
LM340K-5		1.35
LM340K-12		1.35
LM340K-15		1.35
LM340K-24		1.35
LM340T-5		.75
LM340T-12		.75
LM340T-15		.75
LM340T-24		.75
LF347N	14	1.49
LM348N	14	.89
LM350K		4.79
LF351N	8	.59
LF353N	8	.89
LF355N	8	1.09
LF356N	8	1.09
LM358N	8	.59
LM359N	14	1.79
LM370N	14	4.95
LM373N	14	4.95
LM377N	14	1.95
LM380CN	8	1.09
LM380N	14	.89
LM381N	14	1.79
LM382N	14	1.49
LM384N	14	1.95
LM386N-3	8	.89
LM387N	8	1.39
LM389N	18	1.19
LM391N-80	16	1.19
LM392N	8	.59
LM393N	8	.45
LF398N	8	3.95
LM399H		5.95
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NE550A	14	1.95
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LM556N	14	.79
NE558N	16	1.59
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LM565N	14	.99
LM566CN	8	1.49
LM567V	8	.99
NE570N	16	2.95
NE571N	16	2.49
NE592N	14	1.19
LM703CN	8	1.49
LM710N	14	.69
LM711N	14	.79
LM723N	14	.49
LM733N	14	.89
LM739N	14	1.95
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LM1877N-9	14	2.95
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LM2902N	14	.89
LM2907N	14	2.49
LM2917N	8	1.95
LM3900N	14	.59
LM3905CN	8	1.19
LM3909N	8	.89
LM3914N	18	2.39
LM3915N	18	2.39
LM3916N	18	2.39
RC4136N	14	1.25
RC4151NB	8	1.95
RC4193NB	8	1.95
RC4195TK		5.95
LM4250CN	8	1.49
NE5532	8	1.69
NE5534	8	1.39
78L05A		.39
78L12A		.39
79L05A		.59
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LM13600N	16	1.19
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What's New in BATTERIES

Ever since electricity was first discovered, people have been working on ways to store it. Let's take a look at today's battery technology and how you can choose the right battery for your application.

ROBERT GROSSBLATT

THERE'S NO GETTING AROUND THE FACT that as modern electronics becomes more and more sophisticated, batteries have become an increasingly important part of the electronics world. The development of CMOS and all the other low-power technologies have changed even the way we buy batteries—these days, it isn't as easy as just zipping down to the supermarket and pulling the right-sized blister pack from the rack.

Modern batteries come in a mind boggling array of configurations so there are are lots of ways you can categorize them. Probably the most basic categories are "throw-away" and "rechargeable." There can be a major difference in cost, capacity, and characteristics between those two types. Deciding which one is best suited to your particular application requires a good understanding of each. This month, we'll look at the throw-away or disposable battery.

Before we go any further, though, we should point out what we mean by the words "battery" and "cell." A *cell* is the basic building block of a *battery*. A battery is generaly thought of as a single, integral unit made up of one or more cells. If a single cell is packaged with terminations and insulation (such as a "D" cell), it can be correctly called either a battery or a cell.

Disposable batteries

Disposable (non-rechargeable) batteries are available in a huge range of sizes. And as if that wasn't confusing enough, every one of those sizes is available with a variety of electrochemical systems (what we'll call "chemistries"). And even if the voltages of two batteries with different chemistries are the same, just about every other characteristic—from the power capacity to the price—can be different. Like most things, you get what you pay for—more power means more bucks.

So far I haven't said anything earth-shaking, but let me give it a shot: For some applications, batteries that use the more expensive chemistries won't perform any better than cheaper batteries. As we'll soon see, battery life isn't *always* dependant on the battery type.

The voltage of a disposable battery, no matter what the chemistry, is always stamped on the package. What is (almost) never stamped anywhere is the other essential piece of information you need to be able to make an intelligent choice about which battery to use: that is the amp-hour capacity.

The amount of energy that a battery can deliver (sometimes called its service capacity) is usually expressed in amp-hours, or milliamp-hours. It would be nice if the amount of power available from a battery was a fixed amount, kind of like a pail of water. Unfortunately, things aren't that simple and when you're dealing with batteries of *any* kind, linearity is usually out the window.

How much current you can get from a throw-away battery depends on a number of things:

1. The temperature of the battery.
2. The rate of discharge.
3. The chemistry of the battery.
4. The frequency of use.
5. What you call a dead battery.
6. Other stuff.

In order to give us a starting point, we decided to find the short-circuit current of disposable batteries of different sizes and chemistries. Table 1, which lists short-circuit currents, is the result of sacrificing a bunch of new batteries on the alter of science. Even though you would never use a battery in a short-circuit situation, we felt that it would be a good starting point for understanding just how much electricity we're talking about.

Of course, Table 1 doesn't list *all* available battery sizes and chemistries, but the batteries listed are the most commonly used. The figures for other battery sizes, such as "AAA" and "N" will be less than those listed for "AA" cells since they're smaller and, consequently, their energy capacity is less.

There are two main things that stand out when you look over Table 1. The first is that the amount of energy stored in any of the batteries is surprisingly large. Second, you can see that the chemistry of the cell makes a tremendous difference to the total amount of energy that you can pack into a battery.

Battery construction

The internal construction of most throw-away batteries is very similar: Basically you have two electrodes separated by an electrolyte. The construction of a typical disposable cell is shown in Fig. 1 and the chemicals used in the various cells are listed in Table 2. The electrolyte used in all the cells has two basic purposes.

First and foremost, it is the current-conducting medium between the electrodes of the cell. But the chemical reaction that produces the current also generates gas as a by-product. The second main job of the electrolyte is to absorb the gas. The warnings on the side of batteries about excessive drain, recharging, and so on are all related to the gas. If gas is produced faster than it can be absorbed by the electrolyte, the battery will explode. It's as simple as that.

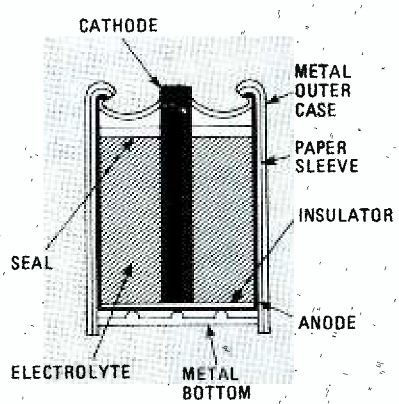

FIG. 1—ZINC-CARBON CELL CONSTRUCTION. This cutaway view shows that the standard cell consists, basically, of two electrodes and electrolyte.

The outer cases of all batteries are made out of steel because the gas creates pressure. (Alkaline batteries, as shown in Fig. 2 also have an inner case.) If the jacket warps and destroys the seal of the case, the electrolyte will dry out and that will be the end of the battery. But that's not the only problem, Some of the chemicals used in the cell are dangerous and a blown seal means that they'll leak. Since a lot of battery changing is done by children, it pays to make sure that you don't abuse the battery.

Battery life

The short-circuit current shown for the batteries in Table 1 is, unfortunately, nothing like the working current. Remember that the unit for measuring battery capacity is the amp-hour—a product of current *and* time. And as mentioned before, the rate of discharge is going to have a major influence on the useful life of the battery. As a general rule for all disposable cells, the more current you pull from it, the shorter its life is going to be. There's a fixed amount of energy available in a new battery and the lower the current drain, the more efficiently the battery can convert its stored energy into electricity. Heavy drain means that some of the energy is going to be transformed into heat, the conductivity of the electrolyte is going to decrease, and other factors are going to all contribute to a significantly shortened battery life.

Figure 3 is a graph showing the discharge rates for both a carbon-zinc and alkaline "C" cell. To obtain data for the graph, an appropriately sized resistor was used to load the cell and the time for the cell voltage to drop one volt was measured. The graph clearly shows that both types of cells are more efficient at lower current drains. It also shows that at low current drains, the efficiency of carbon-zinc and alkaline cells is pretty much the same.

Translated into more practical terms, the less current your circuit needs to operate, the less of a difference there is between the efficiencies of carbon-zinc and alkaline cells. So unless your device draws a lot of current (like a photo flash, etc.,) there's no reason to spend the extra money for alkaline cells.

Don't forget that the graph was plotted by putting the batteries under a *constant*

TABLE 1—TYPICAL DATA

Size	**AA**			**C**		**D**		**9V**		
Type	Zinc	Alkaline	Mercury	Zinc	Alkaline	Zinc	Alkaline	Zinc	Alkaline	Mercury
Rated voltage (volts)	1.50	1.50	1.40	1.50	1.50	1.50	1.50	9.00	9.00	8.40
Measured voltage (volts)	1.49	1.56	1.46	1.50	1.55	1.48	1.58	8.90	9.20	8.41
Short-circuit current (amps)	4.40	7.70	10.3	5.50	9.70	6.80	11.8	0.60	1.40	1.70

TABLE 2—ELECTROCHEMICAL SYSTEMS

Cell type	Anode	Cathode	Electrolyte
Zinc-Carbon	Zinc	Manganese Dioxide	Ammonium and Zinc Chlorides
Alkaline	Zinc	Manganese Dioxide	Potassium Hydroxide
Mercury	Zinc & Mercury	Mercuric Oxide	Potassium Hydroxide & Zinc Oxide

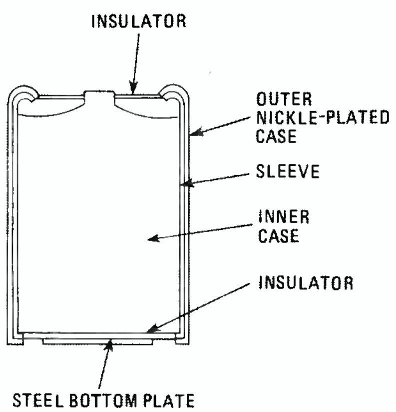

FIG. 2—ALKALINE CELLS are built with an inner case, making them more rugged than zinc-carbon cells.

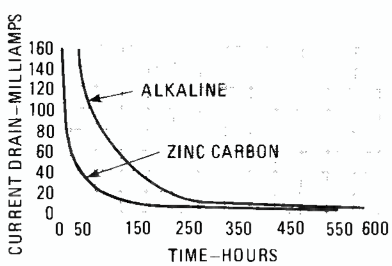

FIG. 3—ENERGY DISCHARGE CURVES for typical alkaline and carbon "C"-sized cells show that for low-current applications, there is not much difference between the two types.

current drain. So the battery life time shown is for a worst-case situation. A more realistic test might include rest time for the battery. The amount of rest time would have a large effect on the life of the battery.

The more rest time the battery has, the longer it's going to last. There's nothing really surprising about that and anybody who owns a car is familiar with the occasionally miraculous recuperative powers a battery will exhibit when it has a bit of time off. Treat the information in Fig. 3 as a guide rather than the gospel. The data there reflects constant current draw—worst case operation. You can only do better.

In Fig. 3, we chose a cutoff point of one volt. If your circuit can operate with less voltage, your results, naturally enough, will be better. If you're feeding raw battery voltage into a regulator, what your cutoff point is will depend on how far the battery voltage is above the regulated voltage. If you can live with a cell voltage of .5 volt, for example, you can reasonably expect your usable battery life to be more than twice as long.

Temperature is a major consideration in judging battery life. It's also one of those things that everyone has a tendency to ignore. Every data sheet I've ever seen lists acceptable temperature ranges for the operation of various devices and everybody I know pays almost no attention to the information. (Maybe it's because we don't have any control over the weather.) In any event, since a battery produces electricity as a result of a chemical reaction, the lower the temperature, the slower the reaction, and the less electricity the battery is going to produce. The effects of that are often quite dramatic. Once again, all of us with cars are familiar with what starting the car is like on a cold winter morning!

The effect of temperature on the capacity of a battery varies with different cell chemistries. Again another general rule: The more constant the voltage of the battery under load, the less effect temperature will have on the ability of the cell to deliver current.

Figure 4 is a graph that compares the two extremes among the common disposable batteries, carbon-zinc and mercury. It's immediately obvious that the zinc-carbon cell is extremely sensitive to temperature—a 30°F rise in temperature will raise the capacity of the battery by more than a third! Mercury cells, on the other hand, are much more stable: The same 30°F rise (from 70°–100°) will have only a 6% effect on the cell. Don't forget that while increasing the temperature *will* raise the capacity of the cell, we've already seen that heat will shorten the life of the cell as well. Put another way, a hot battery will put out a greater amount of current, but it won't last as long as a cooler one. (There's no such thing as a free lunch!)

Mercury cells have a slightly lower open-circuit voltage than carbon-zinc or alkaline cells, but the voltage is almost constant over the life of the cell. As a matter of fact, the voltage is *so* constant that mercury cells used to be used in circuits as precision voltage references. They are still used in equipment, such as smoke alarms, where a constant voltage and high energy capacity are important considerations. Two newer chemistries have been developed that have produced batteries with even *more* stable voltages and higher energy densities. Those are silver-oxide

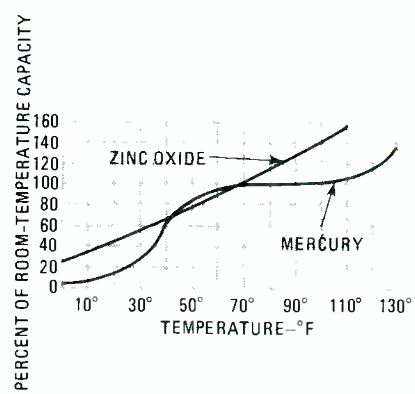

FIG. 4—EFFECT OF TEMPERATURE ON CELL CAPACITY is shown for zinc-oxide and mercury batteries. You can draw more current from a battery at high temperatures, but, of course, the battery won't last as long.

and lithium cells.

The most common use for silver-oxide cells is in digital watches and small calculators. Although their energy density is high, they are usually packaged as small button cells and the available current is, to be generous, limited.

All the batteries we've discussed so far use some form of zinc as the anode material. By changing the cathode and the electrolyte, cells with different energy densities and other characteristics can be made. Recently though, batteries have been introduced that have a different anode material and are the result of more than a decade of research and development. The devices I'm referring to are lithium cells.

Lithium cells

Since lithium is the element with the highest oxidation potential in the periodic table, cells with lithium anodes will have the greatest open-circuit voltage. Just as it is with zinc-based cells, lithium cells can be made with a variety of chemistries and the composition of the cell will determine the operating characteristics of the battery. Table 3 is a list of the possible lithium cell chemistries and the open-circuit voltages they produce.

Lithium-thionyl chloride cells have an open circuit voltage of 3.7 volts (3.4 volts when connected to a 1 kilohm load) and more than ten times the energy density of the lead-acid battery in your car. They have a shelf life of over ten years and a battery that is packaged in a standard "D" size provides an energy capacity of 14 amp-hours!

The energy-discharge curve of those cells is so flat that they come in packages that are made to be soldered directly to circuit boards to provide semi-permanent backup systems for CMOS circuitry and low-power memories. Specially made cells are surgically implanted in the human body to provide long-term power for cardiac pacemakers.

Battery engineers have known for years

TABLE 3—LITHIUM-CELL CHEMISTRIES

Cell chemistry	Open circuit voltage (volts)
Lithium-Thionyl Chloride	3.7
Lithium-Vanadium Pentoxide	3.4
Lithium-Silver Chromate	3.3
Lithium-Manganese Dioxide	3.0
Lithium-Sulfur Dioxide	2.9
Lithium-Carbon Monofluoride	2.8
Lithium-Iodine	2.8
Lithium-Lead Copper Sulfide	2.2
Lithium-Copper Sulfide	2.1
Lithium-Iron Sulfide	1.8
Lithium-Copper Oxide	1.8

about the potential advantages (no pun intended) of lithium-based batteries. The development of a working cell, however, has involved overcoming the kind of problems that are usually associated with the development of any high-energy-density system.

In its simplest terms, a battery is a device that stores a quantity of energy and the secret of a successful design is the ability to provide some means to regulate the release of the energy. The more energy there is in the battery, the more danger there is from a sudden, uncontrolled release of that energy. High current demand, spikes, heat, physical damage, charging current, and overvoltage are a few of the conditions that can lead to potentially dangerous situations.

Heat, as we've already seen, is one of the major enemies of any battery. Lithium has a melting point of 180° C and thermal runaway in the cell caused by physical damage, environmental or circuit conditions can lead to a situation where the entire energy of the cell is released in a split second. That causes what is known in scientific circles as a big problem. Rapid generation of gas will make the battery explode and spew out highly corrosive material and 180° molten lithium—an undesirable situation, to say the least. Modern cell design has overcome those problems by building a pressure-release valve into the seal of the cells and, in case of high temperatures, providing a means for the free lithium at the anode to combine into more stable lithium compounds.

The last two major areas of concern with the lithium cell are really problems with all throw-away batteries—reverse voltage and charging. The difference between the two is that the former problem occurs normally in any series battery setup and the latter problem is the result of circuit conditions.

No two batteries have exactly the same characteristics. Since the action of the cell is chemical, it's impossible to predict *exactly* when the end of battery life will come. If a few cells are connected in series, they will discharge naturally and a time is going to come when one cell will

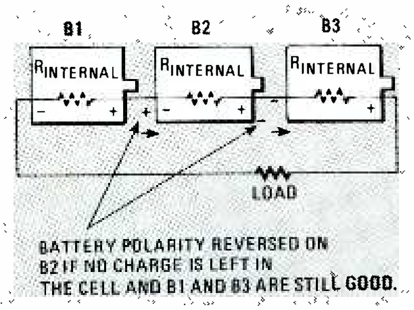

FIG. 5—A REVERSE-VOLTAGE CONDITION occurs because all batteries of the same type do not discharge at the same rate. Above, battery B2 has discharged, and a negative voltage is developed across it.

be completely exhausted while the others are still producing power. As you can see in Fig. 5, current will still flow through the circuit and the dead cell will be acting as a resistor. A reverse voltage will be present at the terminals of the dead battery. Heat will be produced and chemical reactions will take place that can lead to explosive venting. The higher the reverse voltage, the more potentially dangerous the situation is. Battery engineers have designed several methods to handle that hazardous situation.

By making the potential of the cathode less than that of the lithium anode, there will always be some free lithium left when the total potential of the cell is zero. When current flows through the battery in a reverse-voltage situation, it will be carried by lithium ions from the anode instead of ions created by a dangerous chemical reaction in the electrolyte. Altus Corporation has gone one step further to handle that problem by designing an electrochemical switch into all of their batteries. When the battery voltage goes negative, from either reversal or charging, the switch closes, the current through the cell is shunted, and the actual cell voltage is never allowed to exceed −0.1 volt. And that voltage is too low to cause any of the possibly dangerous chemical reactions mentioned above.

Now that we've covered throw-away batteries from Alkaline to Zinc, the obvious question is which battery should you use. Well, we don't have a definite answer: Which battery you need depends on what you want to use it for. Make a list of the parameters of your circuit and then see which battery comes closest to satisfying them.

If your requirements aren't very strict, you can use one of the less expensive batteries such as zinc or alkaline. More exacting needs almost always mean more expensive batteries.

In general, the more expensive the battery, the more predictable its characteristics. Zinc batteries are cheap, but the number of factors that go into determining exactly how the battery will behave is mind boggling. As you go upmarket in price, things become more scientific and clearer. The only advice I can give you is that whichever ones you decide to use, make sure you buy the best constructed throw-away batteries you can. Every battery uses and produces highly corrosive chemicals. A poorly constructed battery can't withstand a lot of abuse and any adverse conditions will cause the cell to rupture—with highly unpredictable and frequently disastrous consequences.

Let's next turn our attention to rechargeable batteries such as nickel-cadmium and, yes, they're still around, lead-acid batteries.

The rechargeables

The history of battery development is the story of trying to squeeze more into less. Research is constantly being done to develop schemes and electrochemical systems that will increase the energy density of the cell and make the energy-discharge curve as flat as possible. In other words, the primary goal of every battery company is to make a battery with the capability of lasting, if not forever, then at least a very long time.

The two basic approaches to the problem can be called the idealistic and the pragmatic. Up to now we've looked at the idealistic approach—designing batteries that can store greater and greater amounts of energy. There are problems with that: The more energy a battery contains, the more engineering it requires to guard against the uncontrolled release of the energy. In the rest of this article we'll concentrate on the more pragmatic approach—designing batteries that can be reused.

The most popular rechargeable batteries use either a nickel-cadmium or lead-acid chemistry. Yes, that's the very same lead-acid chemistry that came into being with running boards and horseless carriages.

Lead-acid batteries

The modern lead-acid cell is a far cry from its predecessors. Its open-circuit voltage is about 2 volts, which means that

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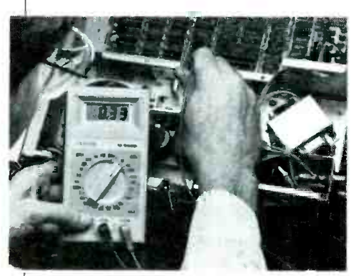

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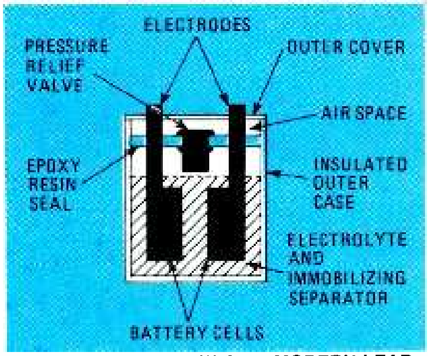


FIG. 6—CUTAWAY VIEW OF A MODERN LEAD-ACID CELL. Some batteries use a gelled electrolyte.

TABLE 4—LEAD-ACID BATTERY CHARGING PARAMETERS

Type of charge	Charging voltage (volts DC per cell)	Charging current (percent of cell capacity)	Charging time
RAPID	2.55 - 2.65	100%	1 - 3 hours
QUICK	2.50 - 2.55	20% - 50%	12 - 20 hours
STANDARD	2.45 - 2.50	10% - 40%	10 - 18 hours
TRICKLE	2.28 - 2.32	10% - 20%	Continuous

it has the second-highest energy capacity of the commercially available batteries, both disposable and rechargeable. Only a lithium-thionyl chloride cell, with an open-circuit voltage of 3.7 volts, has a higher energy-density—and it's not rechargeable! The drawbacks to lead-acid batteries—leakage, highly corrosive acid electrolyte, evaporation, and a host of other problems—have been eliminated in the designs of more modern cells. Lead-acid batteries come in a variety of sizes, voltages, and energy capacities and have characteristics that make them the ideal energy source for applications requiring the use of rechargeable batteries.

So, you may well ask, if they're so wonderful why aren't they more available? The answer to that is...Well, I haven't the vaguest idea and would appreciate finding out why. Possibly the answer has something to do with the ready availability of nickel-cadmium batteries, the other major type of rechargeable battery. Before we start comparing the two technologies, let's take the time to find out how each is used. Once that's done, we'll list the advantages and disadvantages of both types and you'll be able to make your own decisions.

Lead-acid batteries are easy to use. Anyone who owns a car knows that those batteries can operate successfully under the most adverse conditions and are extremely forgiving when it comes to things like accidental deep discharge and constantly repeated partial discharge.

Figure 6 is a cutaway view of a typical lead-acid cell. Although there are variations from manufacturer to manufacturer, most of the batteries use the basic construction shown. The electrolyte is an acid that is permanently sealed in the body of the cell. It's worth nothing at this point that that technique (permanently sealing in the electrolyte) is starting to be found in car batteries as well. Some companies that make lead-acid batteries "immobilize" the electrolyte by gelling it. This means that the cell can be used in any position without any risk of the electrolyte leaking out. Even though the construction of the cell usually involves several heavy-duty seals and double-walled insulation, the acid is extremely corrosive and anything that helps maintain the integrity of the battery is a good idea.

Rechargeable lead-acid batteries are available in voltages ranging from 2 to 24 volts and they can be used in any configuration you want. Unlike some other batteries, you can either parallel them to increase the current or put them in series to increase the voltage. Since the energy density in lead-acid cells is very high, you can get really impressive amounts of power by packing together a number of cells. And how much power the battery can deliver has nothing to do with how the battery was used previously.

A battery that is normally charged after only a small part of its stored energy has been used can still deliver its total power whenever the situation calls for it. That is a common scenario in applications where rechargeable batteries are used as emergency backups in case the primary power fails. Batteries that are constantly charged can similarly always be counted on to deliver their full power if the circumstances require it. In other words, lead-acid batteries have no "memory" of their previous use.

The charging circuits for these batteries can be as simple or sophisticated as you like. They are capable of being charged at extremely high rates if the proper safeguards are taken. How you charge them depends on how you plan to use them. Table 4 gives you the recommended charging rates and other information you'll need to be able to safely recharge the batteries. It's important to stay within the guidelines shown—overcharging can have catastrophic results.

Even though the chemistry of the cells is designed to be reversible (which is what makes the cells rechargeable), overcharging them carries the same sort of dangers as trying to charge the throw away batteries we discussed last month. During the charging cycle of *any* battery, gas is produced. A major functions of the electrolyte is to act as a "depolarizer"—a rather fancy way of saying that it's designed to absorb the gas produced during a charge. However, and this is a really big however, the electrolyte can only absorb gas at a certain rate. If the gas is produced faster that it can be absorbed, then **BOOM!**. Good-bye battery and anything else that happens to be around *and that can include you, too!* Make sure you don't exceed the recommendations for the charging rates and times given in Table 4. A lot of batteries were blown up to compile those figures.

Nickel-cadmium batteries

Nickel-cadmium (NiCd) batteries are the most popular rechargeable batteries on the market today. They are packaged in all the standard sizes and the cell's open-circuit voltage is 1.25 volts (which makes them a close match for most of the applications where throw-away batteries are used.) Prices depend on where you buy them but, in general, it's safe to say that they're more expensive than alkaline and lead-acid batteries, but cheaper than lithium and silver-oxide batteries. The voltage-discharge curve is nice and flat, meaning that the battery will have a constant voltage for most of its discharge cycle. Unlike lead-acid cells, nickel-cadmium cells are not designed to be used in a parallel configuration. The normal method of use is to decide what your current requirements are and then get cells of the needed ampere-hour capacity and connect a number of them in series to build up the voltage you need for your system.

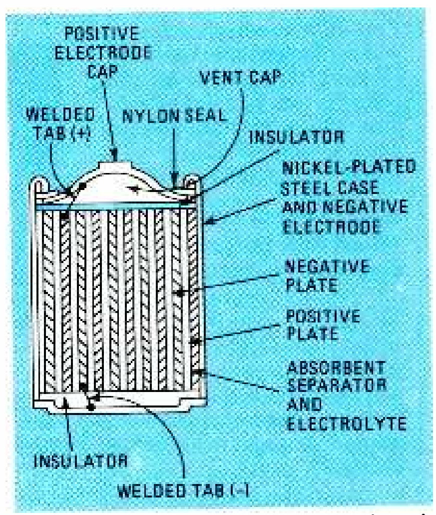


FIG. 7—A NICKEL-CADMIUM CELL consists of nickel and cadmium strips wound together and separated by absorbent nylon.

Figure 7 is a cutaway view of a typical cylindrical NiCd cell. The nickel anode and cadmium cathode are made in strips that are wound together into a coil with an absorbent nylon separator between them. The separator is used to absorb the alkaline electrolyte. It is also permeable to oxygen (the gas produced during the charge cycle). The assembled battery is packed into the outer case, usually made of nickel-plated steel, the external positive and negative contacts are welded to the electrodes, and the cell is finally sealed. The seals keep the electrolyte from drying out and are designed to act as pressure-relief valves. If the internal buildup of gas gets excessive, the seal will open and vent the extra pressure. How well the battery functions afterward depends on how much electrolyte is lost. In any event, you can bet that the battery will be but a shadow of its former self.

The internal resistance of the average NiCd cell is very low—usually less than 100 milliohms—which means they can be used in circuits where high discharge-rates are required. Some NiCd cells, however, are specifically designed with a higher internal resistance that, although lowering the maximum discharge rate, increases the cells ability to retain a charge. Button cells and 9-volt "transistor battery" substitutes are usually manufactured like that. The internal resistance of the cell is a good guide to the charging rate: The higher the value, the lower the charging rate. The most common cause of NiCd cell failure is an improper charging rate.

A dead NiCd will be either an open or short-circuited cell. Open circuits are usually the result of electrolyte loss and this is directly caused by constant rapid discharging, constantly high charge-rates, or anything else that will make the cell blow its seal. Remember that by the time the cell parameters are exceeded enough to make the seal open, the high current rate that caused it in the first place will have made the battery heat up, and that will make the electrolyte evaporate at a greater rate. In any event, there's no way to replace the electrolyte, so if you measure the internal resistance of the battery with a multimeter and find it to be an open circuit, the battery is gone forever.

Short-circuited cells are another story. Sometimes the separator will get ruptured and metallic salts will form a small bridge that shunts the current around the rest of the plate. A high current pulse can burn out the short and the cell can then be charged, since the correct current path has been restored. Commercial "zap" circuits use this technique by charging a large capacitor and then discharging it through the cell. If you monitor the bat-

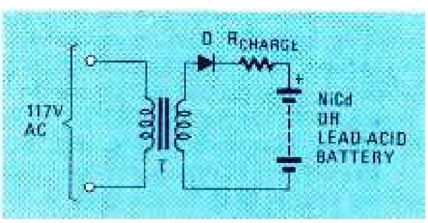


FIG. 8—A SIMPLE CHARGING CIRCUIT for nickel-cadmium or lead-acid batteries.

TABLE 5—NICKEL-CADMIUM BATTERY CHARGING PARAMETERS

Type of charge	Charging voltage (volts per cell)	Charging current (percent of cell capacity)	Charging time
RAPID	Depends on Cell	Depends on Cell	1 - 3 hours
QUICK	2.50 - 3.00	20%	3 - 5 hours
STANDARD	2.50 - 3.00	10%	14 hours
TRICKLE	2.50 - 3.00	5%	Continuous

tery's voltage, you'll see the voltage start to increase as all the internal shorts are cleared out. If the separator has deteriorated in the cell, the battery is beyond salvage and should be replaced.

Recharging batteries

So now that we know everything about lead-acid and nickel-cadmium cells, let's find out about how to charge them. The circuits needed can be as sophisticated—or as simple—as you like. Which circuit you want to use depends on which cells you use, now fast you want to charge them, and how you want to use them.

The simplest charging circuit you can have is illustrated in Fig. 8. Calculating the resistor value and which diode to use is simple. First, let's lay down some general guidelines. The transformer you use should have a voltage at its secondary at least twice the open circuit voltage of the battery you want to charge and the diode should have a PIV (*P*eak *I*nverse *V*oltage) rating at least twice that. The resistor has to be able to handle the charging current at the open-circuit voltage of the battery. To be on the safe side, let's use the voltage of the transformer's secondary. Now that we have those things out of the way, let's use Ohm's law to fill in the blanks.

$$V_{system} = V_{transformer} - (V_{battery} + V_{diode})$$

$$R_{charge} = V_{system}/I_{charge}$$

$$WATTAGE_R = V_{transformer} \times I_{charge}$$

The key here is deciding what you want the charging current (I_{CHARGE}) to be. The rate of current flow through a rechargeable battery is referred to in terms of the total capacity of the cell. The rate of charge or discharge for a particular battery is usually given in the C-rate. The C-rate is the current rate in amperes numerically equal to the rated minimum amp-hour capacity. If the recommended charging rate for a cell is listed as 0.1C, for example, that would tell you that the maximum current you can use to charge the battery is numerically equal to 1/10 the total amp-hour capacity of the cell. If the cell was rated at 500 milliamp-hours, 0.1C would translate into a charging current of 50 milliamps.

Table 5 shows the various rates of charge and how long it will take to fully charge a cell. It's important to remember that not all cells can be charged at the higher rates. Nickel-cadmium cells are too expensive to risk destroying by impatience. All the cells, however can withstand the standard 0.1C rate. But let's get back to our example.

If we're going to charge a 4.8 volt series of batteries that have a 1.2 amp-hour capacity at the standard 0.1C rate and are using a transformer with a 9 volt secondary:

$$V_{system} = V_{transformer} - V_{battery}$$
$$= 9 - 4.8 = 4.2 \text{ Volts}$$

$$I_{charge} = 0.1C = (0.1)(1.2) = 120mA$$

$$R_{charge} = V_{system}/I_{charge}$$
$$= 4.2/.12 = 35\Omega$$

$$WATTAGE_R = (V_{transformer})(I_{charge})$$
$$= 9 \times .12 = 1.08 \text{ WATTS}$$

Finding a resistor with a rating of 1.08 watts is going to be difficult, so let's make a general rule: we'll always bump the value up to the next available size. That means a 35-ohm, 2-watt resistor. The PIV rating of the diode has to be at least twice the transformer secondary or 18 volts and it has to be able to handle at least .12 amps. Any of the family of 1N4xxx diodes is a good choice for the circuit. In this particular case, the 1N4001 is fine. It should be noted that we did not take the voltage drop across the diode into account when we calculated the parameters of the circuit. Since the diode drop is going to be small compared to the other voltages, and our assumptions have built-in safety margins, it can reasonably be ignored. If you're building a charger for battery systems that have lower voltages and are looking for larger charging currents, the diode drop should be considered in calculating the overall system voltage. By the same token, if the charging current you need is really small, the diode's forward resistance will have to be taken into account and subtracted from the calculated value of the current limiting resistor. If the value of the calculated resistor is small enough you can do away with it altogether and let the diode serve as the current limiter.

A more efficient charger can be built using a full-wave rectifier. The math is exactly the same as in our example. Just get the values of the circuit parameters

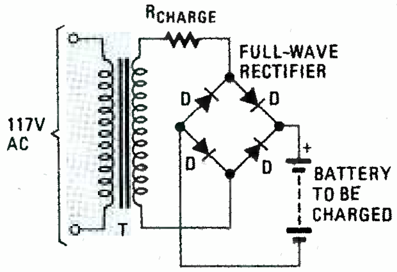


FIG. 9—AS THE BATTERY CHARGES, the current rate will decrease.

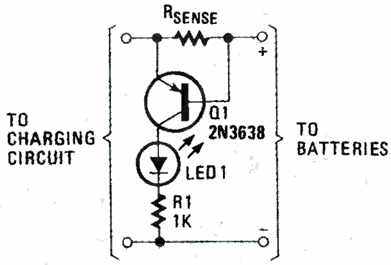


FIG. 10—YOU CAN MONITOR THE CHARGING CURRENT with this simple circuit.

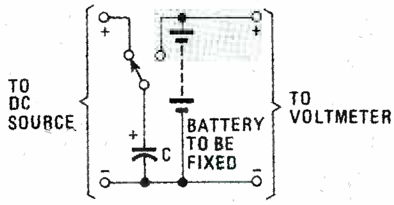


FIG. 11—YOU CAN CLEAR SMALL SHORT-CIRCUITS made up of metallic salts in NiCd batteries.

and plug them into the formulas. More elaborate chargers will monitor the state of charge of the battery and automatically switch over to trickle charging when the battery is fully charged. These circuits are used when the initial charge rate is going to be in the "quick" or "rapid" range. How the circuit is put together will depend on the batteries that are being charged and what the initial charging rate is going to be. The actual design of these circuits is involved because it's a good idea to have several levels of protection for the battery. That way if the primary switchover circuit fails, other parts of the circuit will save the day.

The dangers here shouldn't be minimized. If you overcharge a cell at a high rate of charge, you can, of course, kiss the battery good-bye. But we've already seen that you're running the risk of explosive rupture of the cell from the accumulated gas and that can destroy a lot more than just the battery. I overcharged a 20-milliamp NiCd button cell—the smallest nickel-cadmium battery you can buy. When it exploded it blew a hole in the side of the charger's plastic case! Be warned and be careful to follow the manufacturer's recommendation.

There have been charging circuits published repeatedly in any number of magazines, data books, and so on. Look them up and decide which one you want to use in your particular application. I can offer you a few general rules and a couple of useful tips.

The overall system voltage in your charging circuit will decrease as the cell charges up and the current flowing in the circuit will, naturally enough, start to drop until it reaches a steady state. This is because a discharged cell will rapidly regain enough energy to be at its nominal voltage.

For this reason you shouldn't be alarmed if you measure the current flow in your circuit and find it a lot higher at the beginning of the charge cycle. It will soon drop to a point as close to your calculated value as your component values are close to their calculated values. If your charger is designed for the standard rate, you shouldn't have any problems.

If you use a full-wave rectifier and put the current-limiting resistor between the transformer and the rectifier, you will have a variable-current charger. Current flow will continue to decrease as the cell takes on more and more of a charge. That circuit arrangement is shown in Fig. 9. Figure 10 is a handy circuit that you can use to monitor the current flow.

Basically the small voltage across R_{SENSE} turns on Q1 and the transistor turns on the LED. (Anything you want can be substituted for the LED. A relay, for example could put another resistor in series with the current-limit resistor and cut the charging current down to a trickle charge.) The formula for calculating the value of R_{SENSE} is:

$$R_{SENSE} = 0.65/I_{CHARGE}$$

where 0.65 volt is the voltage needed to turn on the transistor. If you're really a whiz at working out circuit parameters, you could get the value of R_{CHARGE} to equal R_{SENSE} and do the whole job with just one resistor. I can't work things out for you because the values for the components depend on the batteries you use, the charging rate, and many other factors. If you're careful though, you should be able to build yourself a charger that has several charging rates and can automatically switch over to over to trickle charge when a predetermined point is reached.

Rapid charging of cells should not be tried unless the cell is specifically designed to handle very high charging-currents and lots of safeguards are built into the charger. This kind of charging takes place under *very* controlled conditions. The usual method of operation for this kind of charger is to monitor the *temperature* of the cell and switch to a trickle charge, (or completely off), when the temperature of the cell reaches a certain level. Thermistors and other temperature-sensing components monitor the cell and control logic that switches the charger to a lower rate.

We've already discussed how battery "zapping" can be used to try and clear out small internal shorts and revive cells that are apparently dead. Figure 11 is the basic circuit that's used. When the switch is thrown to the left, the capacitor charges, and when the switch is thrown to the right, the capacitor discharges through the theoretically dead battery and, we hope, burns out the small bridges of metallic salts that are shunting the current in the cell.

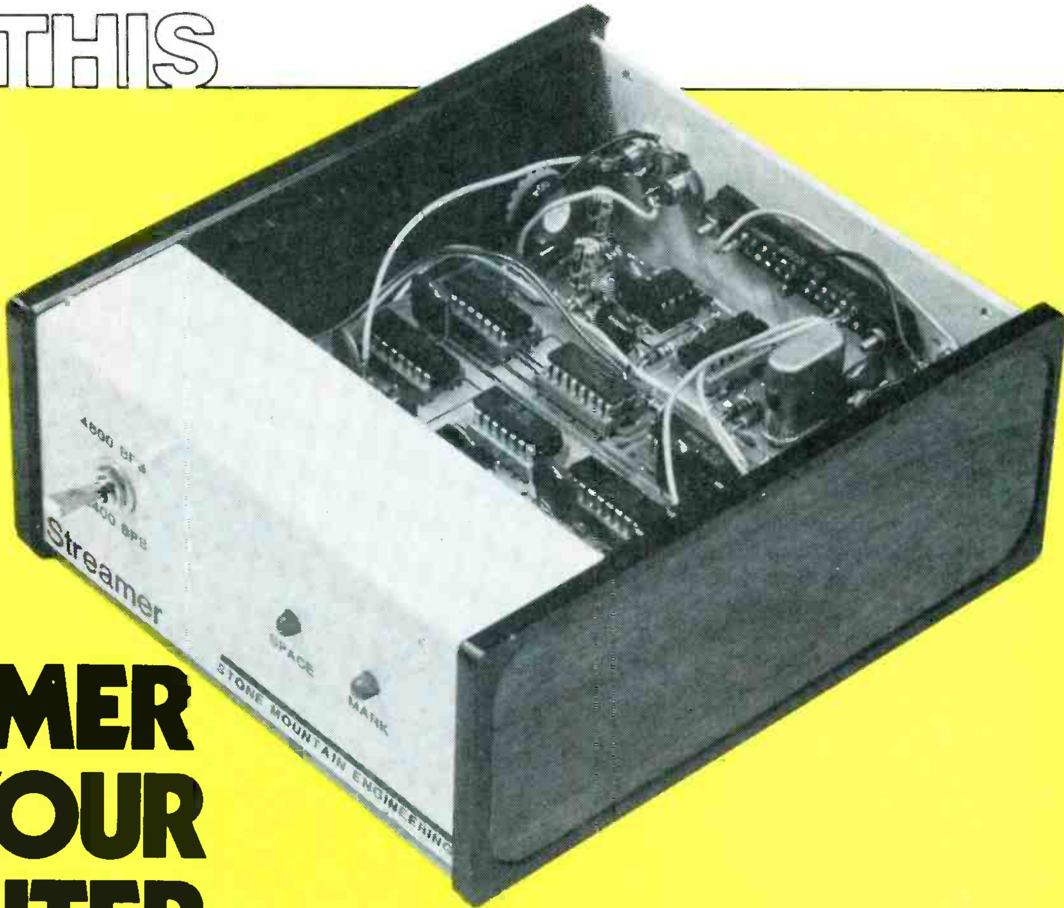
If the cell can be saved, after you blast it a few times you should see the voltage starting to rise on the meter. Once that happens, give the cell a few more hits and then charge it normally. It won't be as good as a good cell, but then again, it won't be as bad as a bad cell. You'll notice that I haven't given you any value for the capacitor. Well, the voltage rating should be *at least* as much as the largest voltage in the system, (either the battery or the source), and the capacitance should be as big as you can get. This is one of those instances where bigger *is* better. The more capacitance you have, the larger the blasting current is going to be and the more chance you're going to have of resuscitating the battery.

Our last helpful hint has to do with one of the most common uses for rechargeable cells: memory retention and emergency backup. There are lots of different ways to design a circuit that will do the job, but the basic idea is shown in Fig. 12. When the DC voltage source is present, the batteries charge through R, the current-limiting resistor (because the diode is reverse biased). When the main power supply

continued on page 96

TABLE 6

Parameter	Lead-acid batteries	Nickel-cadmium batteries
Memory	None	Requires Reconditioning
Current Capacity	Generally in Amperes	Generally in Milliamps
Cost	Moderate	High
Weight	Generally over 1 pound	Generally under 1 pound
Configurations	Parallel or Series	Series Only
Availability	Hard to Find	Available Everywhere
Shelf Life	50% Loss in 8 Months	50% Loss in 3 Months



TAPE STREAMER FOR YOUR COMPUTER

MIKE HUDDLESTON

Are incompatible disk formats keeping you from transferring files from one computer to another? This universal cassette interface can solve that problem. And at 4800 baud, it can do it in a hurry!

THE COST OF MICROCOMPUTER COMPONENTS seems destined to continue to drop. Now you can build or buy computers at prices that seemed unbelievable just a few years ago. But when you add floppy-disk drives, the picture changes. Disk drives haven't dropped in price like other computer hardware has—and it seems likely that disk-drive prices will stay high. Is there a low-cost alternative?

Many of you probably have answered, "audio cassettes." Yes, they can be used but—when compared to disk drives—their slow and unreliable performance leaves much to be desired. We'll show you, however, an easy-to-build cassette interface that may change all that.

That interface, which we'll call a Streamer, is a very fast, highly reliable *universal* audio cassette interface designed to be a low-cost alternative to floppy disks. If your computer has an RS-232 port, you can use the Streamer to transfer data to any other computer similarly equipped. You can transfer *any* program, written on *any* computer, to *any other* computer using a compatible language. For example, the author routinely writes and debugs assembly-language programs at work on an Intel development system, and brings them home on a cassette so that they can be run on his "homebrew" 8080-based computer. He has also transferred BASIC listings from a 6502-based system to cassette so that the programs could be run on his system. (Of course, while the BASIC implementation may vary from one system to another, those differences are usually easy to work around.)

The same thing can be done with other high-level language programs, like FORTRAN or Pascal: The listings can be transferred from one computer to cassette tape and then they can be loaded into your next computer, without worry of disk compatibility. Obviously, doing the same thing in these days of endless 5¼-inch disk formats would be virtually impossible if the systems were not identical.

Streamer basics

The name "Streamer" is computer-shop talk for "streaming tape interface," a term normally used to refer to magnetic-tape systems that are used for disk backup. If you're looking for something to *replace* floppy-disk drives, you should first understand that a streamer is *not* a random-access drive like a floppy disk—the tape moves in one direction only, and files must be accessed sequentially.

The Streamer has no provisions for motor controls, which greatly simplifies its construction and interfacing, but restricts its operation to the manual mode. If you use short (5-minute) cassettes, and put only one program or one file on each, the interface will be easier to use. The cassettes are cheap and reliable, but their random accessibility is limited by the time it takes to remove one cassette and replace it with another.

In the course of designing the Streamer, several encoding techniques—from Kansas City Standard to FSK and PWM—were tried. The method chosen was *Manchester encoding*, which we'll look at in a few moments. Methods of data recovery evolved from the use of filter and phase-locked loops to digital timing. The result is a low-cost but high-performance cassette interface.

Just what do we mean by "high performance?" The data-transfer rate is 4800 baud or bps (*B*its *P*er *S*econd). What that means is that a 16-kilobyte program can be loaded in as little as 38 seconds. The

Streamer is reliable, too—the cassette deck is the limiting factor, so a high-fidelity type deck is recommended. (The author has used a $69 stereo unit for over a year, and has had no permanent errors. When a read error occurs, a simple cleaning of the heads and capstan eliminates the problem.)

Along with its speed and universality, the cassette streamer has another attractive feature: It can be built for about $60. All the electronic parts are standard, and all are available from the vendors who regularly advertise in **Radio-Electronics.**

The Streamer circuit

Figure 1 is a schematic of the interface circuit—we'll start our look at it with the power supply. The circuit requires a voltage supply between 8 and 16 volts DC at a typical current drain of only about 30 mA. That can be supplied by an external wall plug DC supply or it may be "stolen" from the computer or the tape deck. If the computer supply is to be used, the power can be run through pin 25 of the the DB25 connector. If you use a miniature closed-circuit phone jack (J3) and wire it as shown in the schematic, then you can conveniently have your choice of either.

Electrolytic capacitor C14 provides filtering for the raw DC (which powers the RS-232 interface and is the input to the five-volt regulator, IC15). The negative voltage required for RS-232 is furnished by a charge pump: Transistor Q1 is alternately turned on and off by a 76.6-kHz clocking signal provided by IC3, and charges developed across C16 are transferred to C15 through D3. A negative voltage of slightly less magnitude than the positive supply voltage will be developed across C15 for use by the RS-232 output stage.

The circuit's clock is made up of a 2.4576-MHz crystal (XTAL1), and an EXCLUSIVE-OR gate (IC2-d) that's connected as an inverter. The clock's output is divided by IC3, a 4040 ripple counter, for the various frequencies needed by the rest of the circuit. The outputs at pins 2, 3, and 5 of IC3 are baud-rate clocks for the UART (*U*niversal *A*synchronous *R*eceiver/*T*ransmitter).

The UART uses a clock at 16 times the data rate, so the signals at pins 5, 3, and 2 (which are 153.6 76.8, and 38.4 kHz) correspond to UART baud rates of 9600, 4800, and 2400 bits per second, respectively. The UART transmitter (which sends data back to the computer) always runs at 9600 baud, so its TRANSMITTER REGISTER CLOCK, (pin 40) is directly connected to pin 5 of IC3. However, since data from the computer to the Streamer may be either 2400 or 4800 baud, a switch is provided to select different RECEIVER REGISTER CLOCK (pin 17) connections.

RS-232 interfaces are usually crystal controlled. Fortunately, UART's are forgiving of small differences between clocking frequencies. That's important because an RS-232 data stream is continuous—that is, the stop bit of one word is followed immediately by the start bit of the next. Although it would seem there is no margin for error, UART's do allow for some timing variations by accepting stop bits that are either short or long, then re-synchronizing on the following start bit.

PARTS LIST

All resistors ¼ watt, 10% unless otherwise noted
R1—1000 ohms, PC-mount, trimmer potentiometer
R2, R5, R6, R11, R16, R17, R20, R28, R29—1000 ohms
R3, R4, R7, R8, R13, R14, R18, R19, R22, R23, R25, R26, R30—10, 000 ohms
R9—1 Megohm
R10—100,000 ohms
R12, R21, R27—47,000 ohms
R15—10 Megohms
R24—2200 ohms
R31—330 ohms
Capacitors
C1, C4, C13—10 µF, 25 volts, electrolytic
C2, C21—0.001 µF, ceramic disc
C3, C12, C16—0.1 µF ceramic disc
C5, C7, C17, C18, C20, C22, C23, C24—0.01 or .1 µF bypass capacitors (not shown in schematic)
C6, C10—20 pF, ceramic disc
C8, C9—250 pF ceramic disc
C11—5 pF, ceramic disc
C14—100–330 µF, 25 volts, electrolytic
C15—47–220 µF, 25 volts, electrolytic
C19—0.01 µF, ceramic disc
Semiconductors
IC1—LM392 or LM2924 op-amp/comparator
IC2—4070 or 74C86 quad XOR gate
IC3—4040 12-stage binary ripple counter
IC4, IC6—4029 presettable up/down counter
IC5—4520 dual 4-bit synchronous counter
IC7—4011 quad 2-input NAND gate
IC8—4027 dual J-K flip-flop
IC9, IC12—74C74 dual D-type flip-flop
IC10—4015 dual 4-bit static shift register
IC11—6402 CMOS UART (Intersil)
IC13—4021 8-stage static shift register
IC14—LM339 quad comparator
IC15—78L05 low power 5-volt regulator
D1–D5—1N914 or similar
D6, D7—standard red LED
Q1, Q3—2N3904
Q2, Q4—2N3906
XTAL1—2.4576 MHz crystal
MISCELLANEOUS: PC board, enclosure, DPDT switch, DB25 connector, phono jacks for tape deck connectors, hardware, solder, etc.
The following are available from Stone Mountain Engineering Co., PO Box 1573, Stone Mountain, GA, 30086: Printed circuit board, double-sided with plated-through holes, solder masked and silkscreened, for $28; Enclosure, with all holes punched and legends silkscreened, $16; Both PC board and enclosure for $40. All orders must include $1.50 shipping and handling, and Georgia residents please enclose 3% sales tax.

The Streamer extends that idea by sending bits to the cassette tape at a slightly faster rate than its UART receives them. (For an RS-232 input with a data-rate of 4800 bps, the output sent to the tape is at 5486 bps, allowing a timing mismatch of 12.5%.) If the computers baud-rate clock is a little too fast, the Streamer's UART will be overrun. As we mentioned previously, RS-232 can accept stops bits that are either long or short (1½ bits for example). But there is no way to represent a half bit in Manchester encoding. (That will become obvious when we discuss the encoding). So, when the STreamer UART is overrun, it fills its idle bit times with marks (which is the convention), and inserts them as needed to make up an integral number of stop bits.

That accounts for the difference in speed from UART-to-UART, but not for the (typically worse) cassette-playback variations. Tape timing is reliably recovered by timing each bit (Manchester encoding is bit-synchronous), but since the data may play back faster than it was recorded, it may be returned to the computer at a still faster rate. To keep things compatible with RS-232 standards, the bits from the tape are gathered in one at a time, grouped into 8-bit words, and returned to the computer at 9600 bps.

Synchronous counter IC4 provides the Streamer with the tape-data rates. For an RS-232 rate of 4800 bps, the tape, as mentioned earlier, is recorded at 5486 bps; while at 2400 bps, the tape-data rate is 2560 bps. IC4 and IC2-c form a counter that divides by either 7 or 15, depending on the bit rate selected by S1. Since its input is 614.4 kHz, its output will be either 87.77 kHz or 40.96 kHz, sixteen times the tape bit rate. That 16 × bit rate will be used by both the receiver and the transmitter sections.

The receiver

The CMOS UART, IC11, has two separate functional sections; an NRZ receiver with parallel output, and a parallel-input NRZ transmitter. (We'll discuss NRZ encoding—and compare it to the Manchester coding that this interface uses—later on in this article.) The receiver section of the UART, in conjunction with IC12, IC13, IC14-d, IC5-b, IC8-b, and IC7-d comprise the RS-232-to-Manchester converter. Comparator IC14-d, along with its associated discrete components, converts incoming RS-232 data to TTL-level NRZ code. That code is applied to the serial input (pin 20) of the UART receiver section, which is clocked (on pin 17) at the appropriate rate for RS-232 standard compatibility.

An 8-bit shift register (IC13) and a flip-flop (IC12-b) are connected together to

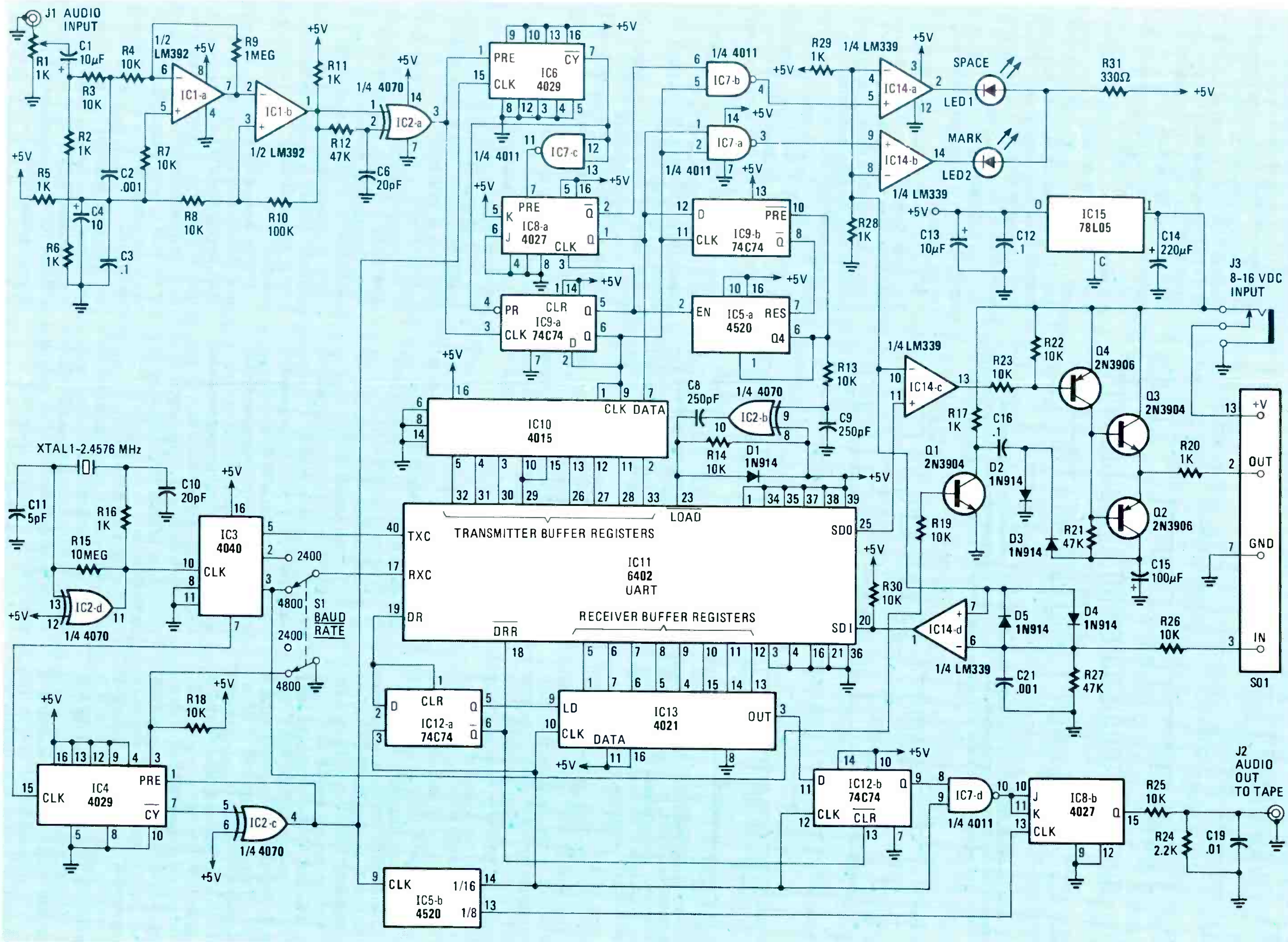


FIG. 1—CASSETTE INTERFACE SCHEMATIC. The main sections of the circuit are the power supply, crystal-controlled clock, RS-232-to-Manchester converter, and the Manchester-to-RS-232 converter. Although not shown, bypass capacitors (0.1 or 0.01 μF) should be located at some of the IC's.

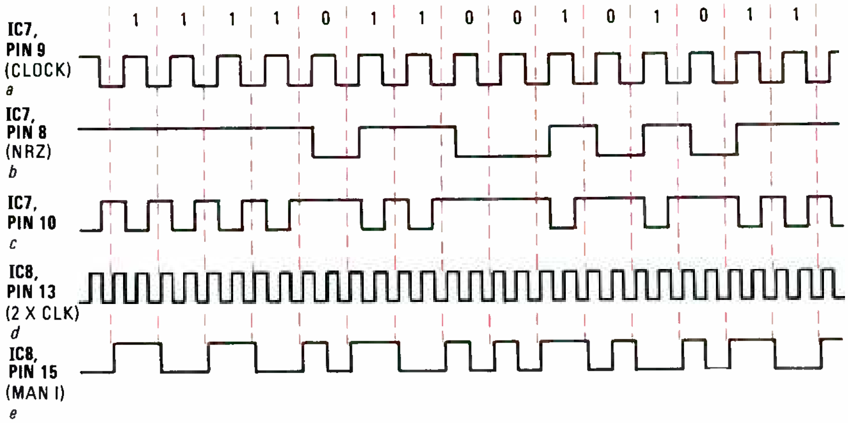


FIG. 2—NRZ-TO-MANCHESTER CONVERSION. The relationship between the two codes may not be apparent, so we should mention that Manchester encoding is based on the presence or absence of transitions—not on high or low levels. We'll discuss both encoding methods in more detail.

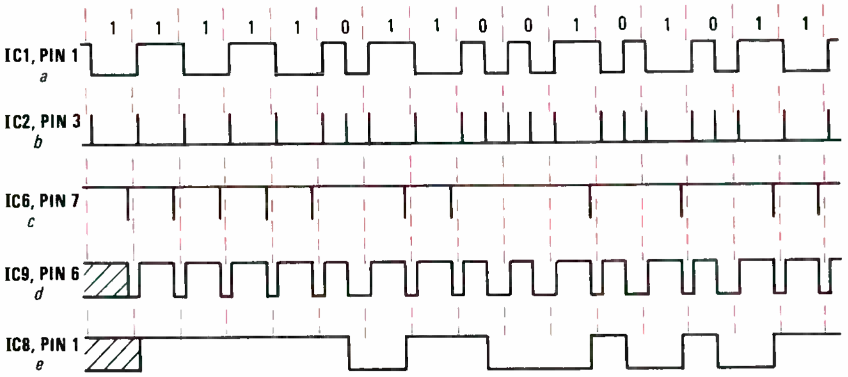


FIG. 3—RECEIVER TIMING DIAGRAM. The Manchester signal received from the tape is shown in *a* (after conditioning by IC1). The output of the transition detector (IC2-a) is shown in *b*. Each transition of the Manchester code produces a positive pulse. The carry output from IC6 (used to determine bit sense) is shown in *c*. The recovered clock is shown in *d*, while the reconstructed NRZ code at the output of IC8-a is shown in *e*.

form a 9-bit parallel-load shift register. Their serial input, pin 11 on IC13, is held high so that marks are clocked through when nothing is parallel-loaded. Once the UART receives a serial word from the computer, IC12-a synchronizes the UART to the tape-data rate from IC5-b, loading IC13 with the eight bits from the UART, and IC12-b with a low for a start bit. The 9-bit register combination now includes a start bit and eight data bits.

The shift register is clocked at the tape-bit rate from IC5-b, pin 14. As soon as it is synchronously loaded by IC12-a, it begins shifting out the loaded data at the tape rate, and follows it with as many marks as necessary until the next word is loaded. The effect of the circuit is that it simply changes the data rate of the received word; the shift register output from IC12-b is still NRZ-encoded, but now at the faster tape-data rate.

An example of this NRZ code is shown in Fig. 2-*b*, along with the tape rate clock in Fig. 2-*a*. Those signals are combined in NAND gate IC7 to produce the signal shown in Fig. 2-*c*. This is applied to IC8-b, which is configured as a toggle flip flop. The flip-flop will toggle whenever the NAND gate output is high and the clock (Fig. 2-*d*) makes a positive transition. The output of this flip flop, shown in Fig, 2-*e*, is the resulting Manchester code. Resistors R24 and R25, with capacitor C19, round off the Manchester bits and reduce their amplitude for application to the tape deck.

The transmitter

The transmitter section of IC11, with the remainder of the circuit components, recover the Manchester code from the cassette and convert it to standard RS-232. The tape signal is applied to R1, a potentiometer that is normally full on. It is then lightly filtered, coupled to an amplifier stage (IC1-a) and passes to a Schmitt trigger (IC1-b), which outputs TTL-level Manchester data at pin 1. If you look at the signal on IC1 pin 1 with an oscilloscope, you'll see the recovered Manchester code, as shown in Fig. 3-*a*. Since that code is sensitive only to transitions (and not to the level), the signal is applied to R12, C6 and IC2-a, a transition detector, which outputs a pulse of about one-microsecond at each transition.

Although we'll be discussing the coding format in detail, for now let us say that marks will be represented here by transitions a full bit time apart, while spaces have transitions occurring twice each bit time. That is illustrated in Fig. 3-*b*.

A 4-bit up/down counter (IC6) is used here as a synchronous one-shot. It is continually clocked at its COUNT input by the 16× tape rate from IC2-c, and outputs a low pulse from its CARRY output (pin 7) whenever it reaches a count of 15. Each time a transition is received, however, the output of IC2-a presets the counter to a value of four. So, as long as spaces are being received, the counter is preset every eight or so clock pulses, so it never reaches the count of 15 before it is again preset to four. Mark bits, on the other hand, have transitions only half as often as space bits, so the counter will reach its terminal count, and output a carry, when a mark is received. Figure 3-*c* is the output from the synchronous one-shot, IC6. Note that the pulses in Fig. 3-*c* indicate the presence of a mark; no output indicates a space.

IC9-a is the clock-recovery flip-flop. The clock signal is derived from the received data; the Streamer's internal clock is used only to test the sense of each bit, in keeping with the bit-synchronous nature of this Manchester code. While spaces are being received, IC2-a pulses two times per bit, toggling IC9-a twice. When a mark is received, its single transition toggles the flip-flop, and then the carry from IC6 presets IC9-a. That corrects the phase of the clock so that, as soon as a mark bi is received, the clock runs in the correc phase. The clock output, IC9-a, pin 6, is shown in Fig. 3-*d*.

The sense of each bit is detected by IC8-a—its output is shown in Fig. 3-*e*. Wired as a R-S flip-flop, IC8-a is set by the mark-detector output from IC6, and reset by clocking from the inverted data clock from IC9-a, pin 5. The clock and data inputs are applied to IC10, which is wired as an 8-bit serial-load shift register. At the end of an eight-bit word, the contents of this shift register are transferred to the UART transmitter, which then outputs NRZ code at 9600 bps.

A bit counter is made up of IC9-b and IC5-a. To understand their operation, assume that IC5-a has its Q4 output (pin 6) high. That output is connected to its ENABLE input, which means that it will not accept any input clocks until Q4 goes low again (i.e., until it is reset). It will remain in that state until a start bit, a space, is detected.

On the next occurrence of a start bit from the bit-sense detector (IC8-a) and a clock from IC9-a, IC9-b's inverted output (pin 8) goes high. Since that output is connected back to the RESET input on IC5-a, the reset operation takes place, which drops the output from Q4 and re-enables the counter. As the Q4 output goes low, IC9-b becomes preset, bringing its inverted output back low and removing the reset command from IC5-a. It is held preset until IC5-a has counted eight clock pulses, corresponding to eight bits being clocked into the shift register. At the ter-

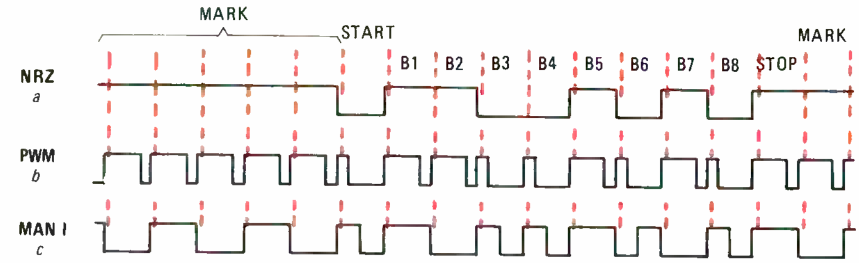


FIG. 4—THREE WAYS TO REPRESENT the serial data stream 11001010. Shown in *a* is NRZ or non-return-to-zero encoding. In *b* is pulse-width modulated encoding, and in *c* is Manchester IA.

minal count of eight, Q4 again goes high, and the operation described above repeats. The Q4 output is also connected through R13 and C9 to IC2-b, which is connected as an inverter. When the inverter output switches low, it is differentiated by C8 and R14, producing a negative pulse on the UART $\overline{\text{LOAD}}$ input. That causes the transmitter shift register to load the data from IC10, and then to commence its transmission to the computer.

The NRZ output from the UART transmitter is conditioned by IC14-c and transistor Q4 to invert the data (RS-232 is inverted) and to swing positive and negative levels, also required by RS-232 conventions. Emitter followers Q2 and Q3 function in a totem-pole configuration to give current drive without unduly loading the supply when operating into a high impedance.

The indicator LED's are turned on when a bit of either mark or space sense is received from the tape. That's accomplished by AND-ing the data lines from IC8-a with the clock line from IC9-a, assuring that, when an LED is on, a real data stream is being processed. When data is being decoded, both LED's will flicker at a high rate, giving the appearance of both being on. During an idle time, when the NRZ data would be marking, only the MARK LED will be on; if the tape is blank, neither will come on.

Manchester encoding

Manchester coding is a method of phase-encoding serial data. It was introduced during the early days of data recording as a means of efficiently including clocking information with transmitted data. The technique was invented at Manchester University in England to be used in Ferranti computers and it is in widespread use today in both the computer and the communications industries.

Non-return-to-zero, or NRZ, code is by far the most common means of serial data interchange between computers and their peripherals. Whether represented by TTL levels, RS-232 levels, or current loops, the conventions are the same: An idle line stays at a mark level; a data word is represented by a specific number of bits, mark or space, and each data word is preceded by a start bit (which is a space) and followed by one or more stop bits (which are marks). The word size is not specified, but is usually five to eight bits, and may or may not contain a parity bit for error detection.

There are several good reasons for the proliferation of NRZ code. First, it's easy to understand. (If you take a look at Fig. 4, you'll probably be able to immediately see what's going on with the NRZ code before we even discuss it.) Second, NRZ is supported by numerous LSI communications controllers (UART's, USART's, etc.). Third, almost every peripheral available uses it.

One characteristic of NRZ code is that it must be capable of preserving very long periods of idleness or marking. That implies that the link must have a low-end frequency response reaching down to DC. In the typical data-equipment environment, that requirement is met by hard-wired connections. But when connections without DC continuity are used for data, NRZ code cannot be used. Telephone lines and audio tape, for example, where frequency response drops off below about 30 Hz, are two applications for which raw NRZ code is unsuitable. Due to the very nature of NRZ coding, there is only one place in an entire transmitted word where bit timing may be recovered during reception. That is the initial mark-to-space transition at the beginning of the start bit. Since all other bits in the word are undefined (and indeed, may be all spaces or

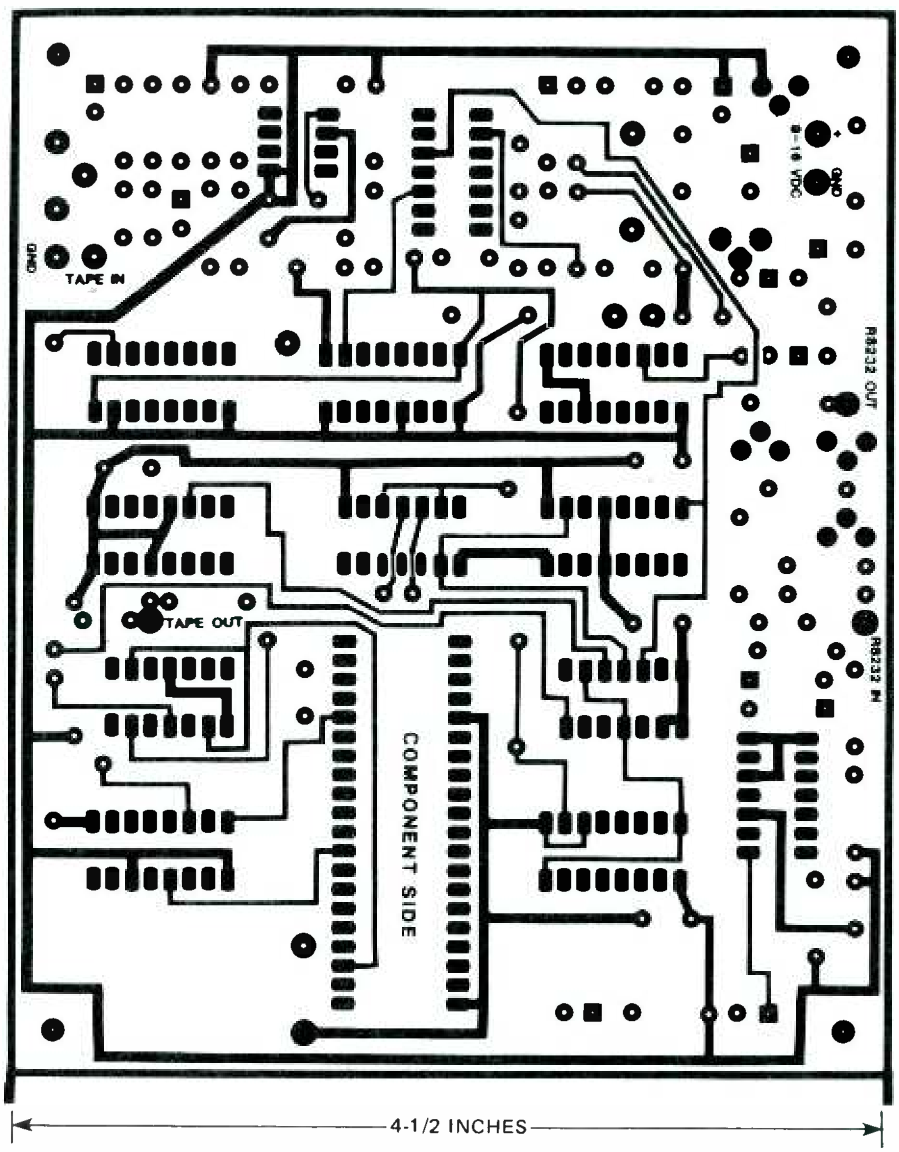


FIG. 5—THE COMPONENT SIDE of the double-sided streamer circuit board. Note that the square pads represent the positive end of electrolytic capacitors or the banded (cathode) end of diodes.

all marks), it is easy to see that there are simply no other places in the word that can be predicted. That technique is known as *word synchronization*, as all the bits of the word are recovered by timing from that one known point.

Word synchronization implies that timing errors are cumulative: The longer the data word, the more likely the chances for recovery errors. Recognizing that, devices using NRZ coding generally are designed with crystal-controlled clocks at each end of the link, and word length is kept under ten or so bits in order to avoid timing errors.

From the above, we can see that NRZ coding is unacceptable for audio magnetic media: Audio tape devices are not responsive to DC levels, and the lack of stability of their motor-driven capstans precludes precision clocking. An audio data interface, then, must convert NRZ marks and spaces to signals that can be successfully recorded and recovered. In addition, the interface must compensate for the tape device's inherent timing instability.

Historically, the most common method of audio data recording has been to represent NRZ data with two audio tones, one for mark, and another for space. (That modulation technique is known as FSK or *F*requency *S*hift *K*eying.) Those two frequencies are then detected during playback with either high-Q audio filters or phase-locked loops. With either technique, some individual tuning is required, and the higher the data rate, the more critical the tuning becomes.

However, if you're not interested in maximum performance, then it's possible to design quite simple interfaces. The combination of modulating fairly high audio tones with low data rates allows greatly simplified (and thus lower-cost) decoder hardware to be used. The old Kansas City Standard—300 baud 1200- and 2400-Hz audio tones—is a prime example.

The maximum frequency of the audio tones is limited by the available bandwidth of the recording medium. In order to maximize data rate, the available bandwidth should be made use of and the recording format should be bandwidth-efficient. (In other words, the ratio of the higher audio-tone frequency to the data rate should be low.) The 300-baud format discussed above uses a 2400 Hz maximum frequency, indicating a frequency to data ratio of 8 to 1. The Manchester code used by the Streamer sports a ratio of 1 to 1—an eight-fold increase in efficiency. By doubling the modulation frequency, a 16× speed advantage is attained!

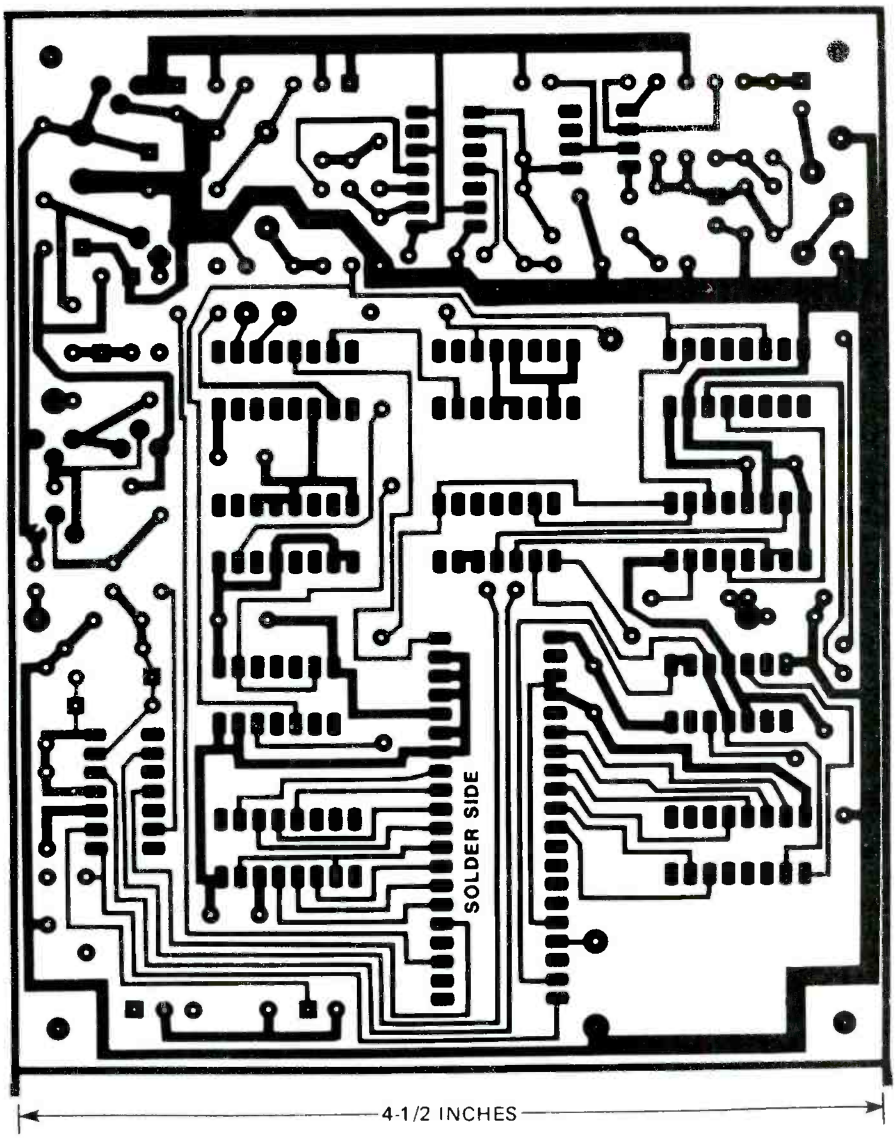


FIG. 6—THE SOLDER SIDE of the streamer circuit board. Note that square pads are used here for the same reason as on the component side.

Building the Streamer

Now that we understand the theory of Manchester encoding and of the Streamer's circuit, we can get on to building it. Because of the large number of discrete components, it is highly recommended that the Streamer be built on a printed circuit board. Full scale artwork for the component and foil sides of a suitable circuit board is shown in Fig. 5 and 6. If you can't make your own board, you can buy a pre-etched, drilled, silk-screened, and solder-masked board from the source listed in the parts list.

The parts-placement diagram for the Streamer is shown in Fig. 7. When you install the parts, use a clean, low-power soldering iron. The finer the tip, the better. If you purchase a PC board, you'll note that it has a solder mask, so the chances of the solder inadvertently bridging is greatly reduced. Even so, it pays to be careful. If you make your own board, take particular care to avoid solder bridges. They may be hard to find and will definitely keep the unit from operating.

There is nothing critical about the components. Everything is available through vendors that regularly advertise in **Radio-Electronics**. Normal precautions should be taken in the handling of the CMOS IC's as they can be destroyed by static charges.

None of the capacitors are used for timing, so they may have tolerances as low as 20% without ill effects. The power-supply filter capacitors, C14 and C15, can be as large as you want (as long as they fit on the board!). If the DC supply isn't filtered, however, C14 must be at least 220 µF to smooth out the ripples.

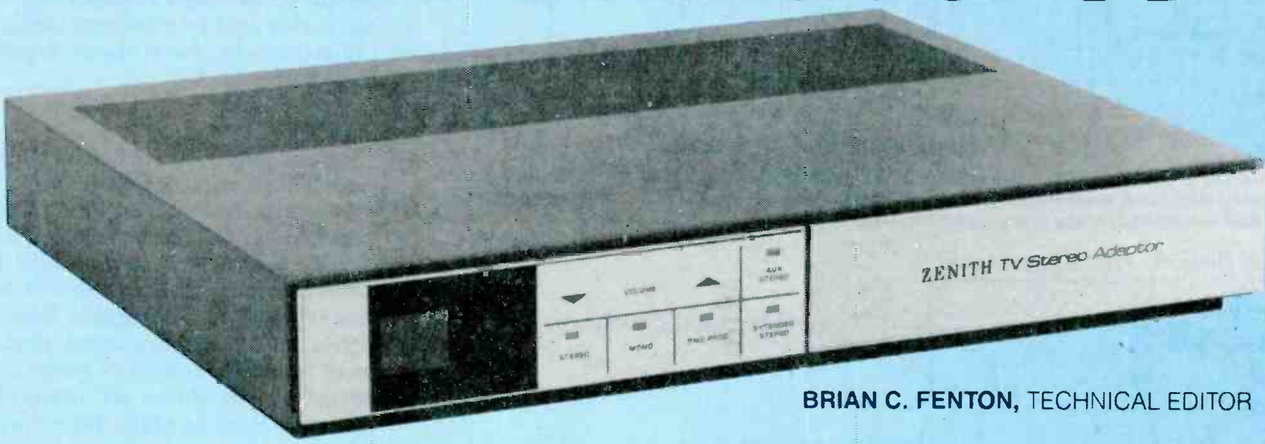
The Streamer is overdesigned with power-supply bypass capacitors. While it never hurts to include them, feel free to eliminate three or four if you want—it won't impair the circuit's operation. Note that the bypass capacitors—although listed in the Parts List—were not shown in Fig. 1. They are, however, shown in the parts-placement diagram.

The resistor values also are not critical. All resistors may have 10% tolerance, and you may even go to either the next higher or next lower standard value, if it's more convenient. The PC-mounted potentiom-

continued on page 94

ALL ABOUT

STEREO Sound For TV



BRIAN C. FENTON, TECHNICAL EDITOR

A recent FCC decision has set the stage for multichannel television sound. Here's a look at that decision, its technical aspects, and the new dimension in TV sound that it makes possible.

STEREO TV IS FINALLY HERE! IT'S THE most exciting development in television since the introduction of the videodisc player and VCR. Interestingly enough, while the idea of stereo television has been on the minds of the industry for some time, it was the *consumer's* interest—stimulated by videodisc players and VCR's—that was the driving force behind making it a reality. But *M*ultichannel *T*elevision *S*ound (MTS) is not just stereo TV—it's a completely new way of using television's audio signal.

The FCC decision

The Federal Communications Commission authorized multichannel TV sound in late March 1984 by adopting new, very general rules regarding TV audio signals. As a result of that action, stereo TV sound, as well as second-language programming and many other services, are now possible.

As has been the the FCC's policy of late, the Commission did not adopt a single system as a stereo TV standard. Remember the FCC's "let the marketplace decide" decision on AM stereo, and the uncertainty and inaction in the marketplace that it caused. (AM stereo is yet to really get off the ground.) But thanks to the television industry, that's not about to happen to stereo TV!

The main difference between the two cases is that the industry—with the knowledge of what happened with AM stereo—presented a single proposal to the FCC for adoption. Both broadcasters and equipment manufacturers worked together through the EIA (Electronic Industries Association) whose Broadcast Television Systems Committee (BTSC) worked 5 years selecting a system as a standard. The transmission system that was chosen by the BTSC was developed by Zenith, and the noise reduction system was developed by dbx Corporation. (Those were selected over transmission systems developed by the Electronic Industries Association of Japan and Telesonics Systems, Inc. and noise-reduction systems developed by Dolby and CBS Laboratories.)

Together, the Zenith transmission system and the dbx-TV noise reduction system make up the BTSC multichannel television sound or MTS system. We'll take a close look at both systems a little later on in this article.

Even though the FCC was presented with a proposal for a single MTS system, the Commission's decision still followed an "open marketplace" policy. That was based on the (correct) belief that MTS technology will continue to advance beyond the BTSC system. However, because the FCC was aware both of what happened with AM stereo and the industry's proven desire for a single standard, they endorsed the BTSC system by protecting its *pilot tone*. That means that the pilot frequency may be used only by broadcasters using the BTSC system. By restricting the use of the pilot frequency, BTSC-type receivers are protected from falsely detecting other MTS formats, but any other MTS system can be used *if the marketplace calls for it*.

The BTSC system

Before late March, 1984, the TV-audio baseband—the band of frequencies from 0 to 120 kHz that contains a TV signal's audio information—was limited to carrying only audio in the *main channel* (the portion of the baseband from 50 Hz to 15 kHz). Now, thanks to the FCC decision, the audio baseband is virtually unregulated. For most of us, that means that we can now listen to TV in stereo or in a second language. But for broadcasters, it means a number of options.

Figure 1 shows a "fully loaded" MTS audio baseband. We'll call it stereo + SAP service. The frequency-modulated main-channel audio is contained from 50 to 15 kHz, just as it is in any TV broadcast. What is different from conventional TV signals is that the baseband also includes an amplitude-modulated *stereo-difference* subcarrier, a pilot signal, a SAP (*S*econd-*A*udio-*P*rogram) channel, and a *professional channel*. But that is only *one* of the possible configurations. Figure 2 shows three other possible configurations: stereo service without SAP capability, mono service with SAP capability, and mono service without SAP capability. Note that each configuration leaves room for a professional channel.

The professional channel can be used for a wide variety of non-program-related uses. A TV station can use it to relay broadcast materials to other stations, to communicate with remote crews, etc. But the professional channel could also be used to transmit signals to *you*—or, to be more precise—to your TV receiver. For

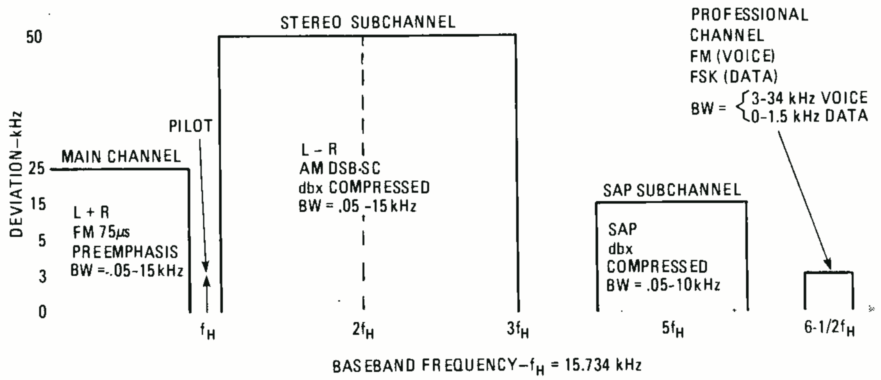


FIG. 1—THE "FULLY LOADED" AUDIO BASEBAND for multichannel television sound contains the frequency-modulated main channel, amplitude-modulated stereo subchannel, an amplitude-modulated SAP subchannel, and a professional channel.

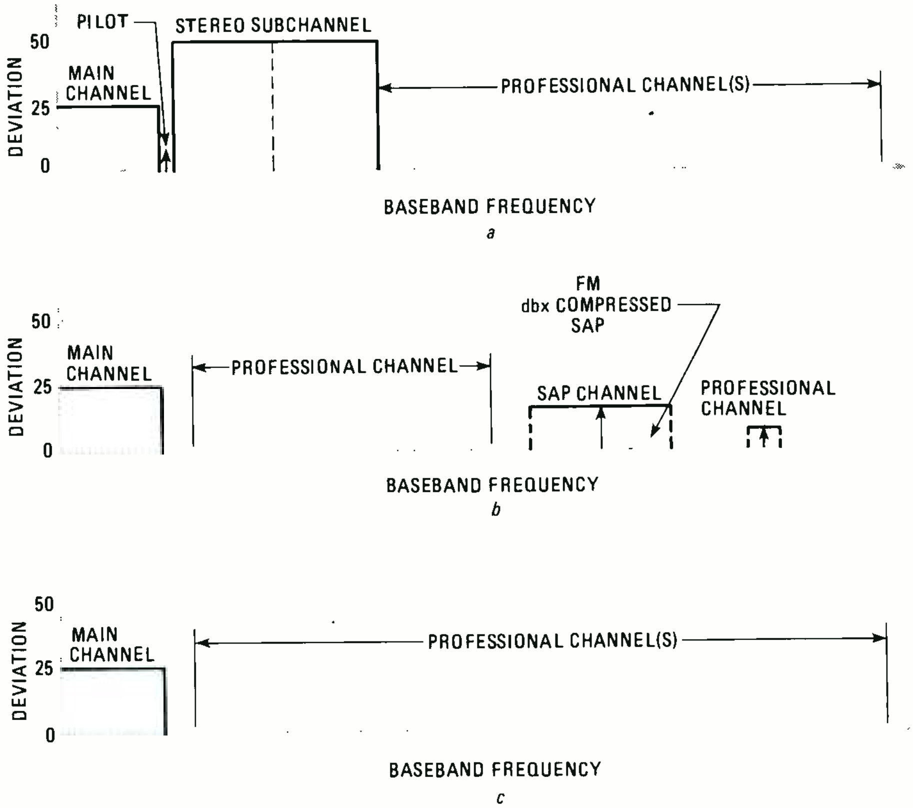


FIG. 2—THE AUDIO BASEBAND can be configured in many ways under the new regulations. Here we see stereo-only service (*a*), mono service with SAP (*b*), and mono service (*c*). Note that each configuration leaves room for a professional channel. That professional channel can be used for a variety of non-program related applications.

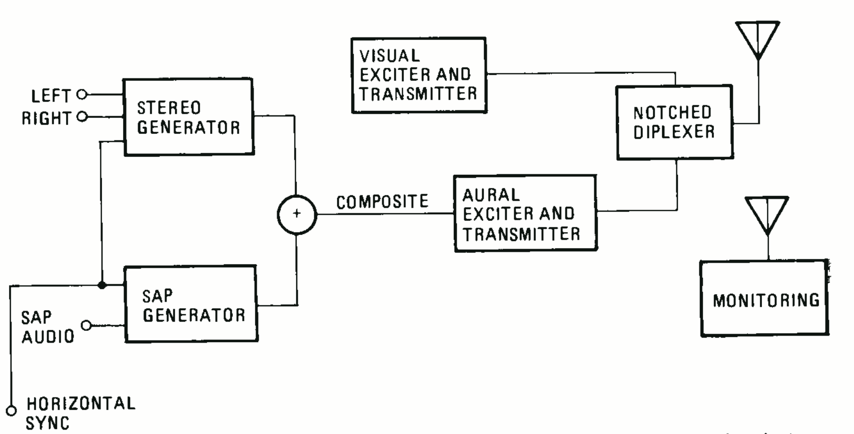


FIG. 3—BTSC TRANSMISSION SYSTEM. The signal that drives the audio (aural) transmitter is the sum of the stereo-and SAP-generator outputs. A diplexer is used so that the video transmitter and audio transmitter can use the same antenna. The notch filter at 4.5 MHz reduces one source of audio buzz: the direct spillover of video sideband components into the audio carrier spectrum.

example, a signal could be sent to turn on receiver noise-reduction circuitry. Another—though unlikely—possibility is that a TV station could transmit control signals to your VCR so that it wouldn't record commercials.

The professional channel is not restricted to carrying TV-related signals; it can also be used for subsidiary communications services (much like the broadcast FM SCA services).

It's really here!

Before we go into some of the theory behind MTS, let us emphasize that stereo television and multichannel TV sound are here for real. The first commercial television broadcast with stereo sound took place during coverage of the 1984 Summer Olympics in Los Angeles. Television digest, the industry newsletter, notes that as of November 1, 1984, 7 stations were on the air with almost 200 others either testing or planning MTS. Table 1 is a list of those stations.

The Zenith transmission system

The MTS system that was chosen by the industry and endorsed by the FCC is made up of a transmission system and a noise-reduction system. The transmission system selected was developed by Zentih.

An important aspect of the Zenith system is that it is compatibile with the existing NTSC standard. That is important because any MTS system not compatible with existing TV's would be useless—neither the broadcasters nor the equipment manufacturers would support it.

In order for MTS signals to be compatible with conventional signals, the main channel must be compatible. Therefore, the main channel of the Zenith system signal contains the monaural signal, which is the sum of the left- and right-channel signals. (We'll refer to the monaural signal as the *stereo sum* or L + R signal). That L + R signal frequency-modulates the TV carrier in the same way that a conventional mono signal does.

The the *stereo difference* signal (L – R) amplitude-modulates a subcarrier centered at a 31.468 MHz—twice the horizontal scanning frequency, $2f_H$. A pilot signal, which is used by the receiver to decode the stereo information, is located in the audio baseband at the horizontal scanning frequency, f_H (15,734 kHz). As we mentioned previously, while the rest of the audio baseband is virtually unregulated, that pilot frequency is protected under FCC rules.

A standard (mono) TV set will ignore everything but the main channel and will recover the L + R audio just as it would any mono signal. A stereo-capable set, however, will use the pilot signal both to recognize that a stereo signal is present and to generate a carrier for decoding the L – R component.

TABLE 1—MTS BROADCASTERS

All stations stereo, non-SAP, unless otherwise indicated in footnote.

Now broadcasting regularly in stereo:

WTTW	Chicago, IL	(PBS)
WTIC-TV	Hartford, CT	(ind.)
KTLA	Los Angeles, CA	(ind.)[a]
KIRO-TV	Seattle, WA	(CBS)
KOMO-TV	Seattle, WA	(ABC)
WDBB-TV	Tuscaloosa, AL	(ind.)
WTXX	Waterbury, CT	(ind.)

Planning fall 1984 start:

WZTZ-TV	Boston, MA	(ind.)
WEDH	Hartford, CT	(PBS)
WFSB	Hartford, CT	(CBS)
WTLV	Jacksonville, FL	(ABC))
KABC-TV	Los Angeles, CA	(ABC)
KTLA	Los Angeles, CA	(ind.)[a]
KMSO-TV	Missoula, MT*	(CBS)[f]
WNET	N.Y.-Newark	(PBS)
KATU	Portland, MT	(ABC)
KRBK-TV	Sacramento, CA	(ind.)
KPLR-TV	St. Louis, MO	(ind.)
KSL-TV	Salt Lake City, MO	(CBS)
WMHT	Schenectady-Albany-Troy, NY	(PBS)
WTVG	Toledo, OH	(NBC)
WNJT	Trenton, NJ	(PBS)[b]
KPOL	Tucson, AZ*	(ind.)[f]

Planning winter 1984-85 start:

KTVA	Anchorage, AK	(CBS)
WGNX-TV	Atlanta, GA	(ind.)
WBZ-TV	Boston, MA	(NBC)
WVIZ-TV	Cleveland, OH	(PBS)
KERA-TV	Dallas, TX	(PBS)[a]
KOOD	Hays-Russell-Gt. Bend, KS	(PBS)
KVVU-TV	Henderson-Las Vegas, NV	(ind.)
WIUD	Lakeland, FL*	(ind.)
WMFP	Lawrence, MA*	(ind.)
WPBT	Miami, FL	(PBS)
WYES-TV	New Orleans, LA	(PBS)
WEDN	Norwich, CT	(PBS)
KTIE-TV	Oxnard, CA*	(ind.)
WPSD-TV	Paducah, KY	(NBC)
WEEK-TV	Peoria, IL	(NBC)
KPHO-TV	Phoenix, AZ	(ind.)
KSBW-TV	Salinas-Monterey, CA	(NBC)
KUED	Salt Lake City, UT	(PBS)[a]
KSAT-TV	San Antonio, TX	(ABC)[c]
KOVR-TV	Sacramento, CA	(ABC)
WFSU-TV	Tallahassee, TN	(PBS)

Planning spring 1985 start:

WTBS	Atlanta, GA	(ind.)
WJZ-TV	Baltimore, MD	(ABC)[a]
WTTO	Birmingham, AL	(ind.)
KWHP	Boise, ID*	(ind.)
new,	Cedar City, UT*	
WMAQ-TV	Chicago, IL	(NBC)
WCET	Cincinnati, OH	(PBS)[a]
KHBS	Ft. Smith, AR	(ABC)[e]
KMSG	Fresno (Sanger), CA*	(ind.)
WXII	Greensboro-High Point-Winston-Salem, NC	(NBC)
WITF-TV	Harrisburg, PA	(PBS)
new,	Idaho Falls, ID*	(ind.)
WFYI	Indianapolis, IN	(ind.)
WRLR	Las Vegas, NV*	(ind.)
WIYE	Leesburg, FL	(ind.)
KNBC-TV	Los Angeles, CA	(NBC)
KWHY-TV	Los Angeles, CA	(ind.)
WBFS-TV	Miami, FL*	(ind.)[a]
WMVS	Milwaukee, WI	(PBS)[a]
WMVT	Milwaukee, WI	(PBS)[a]
WLCT	New London,* CT	(ind.)
WNOL-TV	New Orleans, LA	(ind.)
WNBC-TV	New York, NY	(NBC)[a]
WCFE-TV	Plattsburg, NY	(PBS)[a]
WXXI	Rochester, NY	(PBS)
KCRA-TV	Sacramento, CA	(NBC)
KETC	St. Louis, MO	(PBS)
WOIO	Shaker Heights, OH*	(ind.)
KSMW	Spokane, WA*	(ind.)
WACO	Waco, TX*	(ind.)
WRC-TV	Washington, DC	(NBC)
WHYY-TV	Wilmington-Phila., PA	(PBS)

Planning start in late 1985:

KNME-TV	Albuquerque, NM	(PBS)[f]
KOAT-TV	Albuquerque, NM	(ABC)
KTUU-TV	Anchorage, AK	(NBC)
WATL-TV	Atlanta, GA	(ind.)
WCBB	Augusta-Lewiston-Portland, ME	(PBS)
WSKG	Binghamton, NY	(PBS)[a]
WGBH-TV	Boston, MA	(PBS)[a]
WNEV-TV	Boston, MA	(CBS)
WNJS	Camden, NJ	(PBS)[e]
WKYC-TV	Cleveland, OH	(NBC)
KLBY	Colby, KS*	(ind.)
WCMH-TV	Columbus, OH	(NBC)
WOSU-TV	Columbus, OH	(PBS)
WTVN-TV	Columbus, OH	(ABC)
WJBK-TV	Detroit, MI	(CBS)[a]
WKBD-TV	Detroit, MI	(ind.)
WTVS	Detroit, MI	(PBS)[f]
WXYZ-TV	Detroit, MI	(ABC)
KTSM-TV	El Paso, TX	(NBC)
KVIA-TV	El Paso, TX	(ABC)[a]
KJEO	Fresno, CA	(ABC)[c]
WLRE	Green Bay, WI	(ind.)
KHOU-TV	Houston, TX	(CBS)[a]
WVSN-TV	Humacao, PR*	(ind.)
KIFI-TV	Idaho Falls, ID	(NBC)[e]
WJXT	Jacksonville, FL	(CBS)
KATV	Little Rock, AR	(ABC)
KHJ-TV	Los Angeles, CA	(ind.)[a]
WMAZ-TV	Macon, GA	(CBS)
WCIX-TV	Miami, FL	(ind.)
WCCO-TV	Minneapolis-St. Paul, MN	(CBS)[f]
WNJM	Montclair, NJ	(PBS)[e]
WNJB	New Brunswick, NJ	(PBS)[e]
WEDY	New Haven, CT	(PBS)
WNYC-TV	NY, NY	(PBS)
KETV	Omaha, NE	(ABC)
WOFL	Orlando, FL	(ind.)[a]
WXEX-TV	Richm'd-Petersb'g, VA	(ABC)
KTSP-TV	Phoenix, AZ	(CBS)
WPBO-TV	Portsmouth, OH	(PBS)
KBYU-TV	Provo, UT	(PBS)
KTSL	Sacramento, CA	(ind.)[a]
KSDK	St. Louis, MO	(NBC)[e]
KRON-TV	San Francisco, CA	(NBC)[f]
KTEH	San Jose, CA	(PBS)[e]
WSJU	San Juan, PR*	(ind.)[e]
WMHT	Schenectady-Albany-Troy, NY	(PBS)
WVIA-TV	Scranton-Wilkes Barre-Hazleton, PA	(PBS)
KTBS-TV	Shreveport, LA	(ABC)[e]
KREM-TV	Spokane, WA	(CBS)
KSCH-TV	Stockton-Sacramento* CA	(ind.)
WEDU	Tampa-St. Petersburg, FL	(PBS)
KCEN-TV	Temple-Waco, TX	(NBC)[a]
WNJT	Trenton, NJ	(PBS)[d]
KUAT-TV	Tucson, AZ	(PBS)
WILL-TV	Urbana-Champaign, IL	(PBS)[e]
KMPH	Visalia-Fresno, CA	(ind.)
WPEC	West Palm Beach, FL	(ABC)[a]

Planning 1986 start:

WSBK	Boston, MA	(ind.)
WUFT	Gainesville, FL	(PBS)
WJKS-TV	Jacksonville, FL	(NBC)
WFMY-TV	Greensboro-High Point-Winston-Salem, NC	(CBS)
KSHB-TV	Kansas City, MO	(ind.)
WHA-TV	Madison, WI	(PBS)
WFTV	Orlando, FL	(ABC)
KDNL-TV	St. Louis, MO	(ind.)
WGGB-TV	Spfld.-Holyoke, MA	(ABC)

Planning start after 1986:

KMTF	Fresno, CA	(PBS)
WLFI-TV	Lafayette-Kokomo, IN	(CBS)
WNMU-TV	Marquette, MI	(PBS)
WITI-TV	Milwaukee, WI	(CBS)
WTSP-TV	St. Petersburg-Tampa, FL	(ABC)
KVIE	Sacramento, CA	(PBS)[a]
KCTS-TV	Seattle, WA	(PBS)

Planning MTS, no date:

WNUV-TV	Baltimore, MD	(ind.)
WRBT	Baton Rouge, LA	(NBC)
WBNG-TV	Binghamton, NY	(CBS)[e]
WBMG	Birmingham, AL	(CBS)
KFYR-TV	Bismarck, ND	(NBC)
KTVB	Boise, ID	(NBC)
KMGH-TV	Denver, CO	(CBS)[a]
WGPR-TV	Detroit, MI	(ind.)
WFIQ	Florence, AL	(PBS)
WSWP-TV	Grandview, WV	(PBS)
KHON-TV	Honolulu, HI	(NBC)
WISH-TV	Indianapolis, IN	(CBS)
WJCT	Jacksonville, FL	(PBS)
KHGI-TV	Kearney-Hastings, NE	(ABC)
KARK-TV	Little Rock, AR	(NBC)
KTHV	Little Rock, AR	(CBS)[e]
KCET	Los Angeles, CA	(PBS)
WISN-TV	Milwaukee, WI	(ABC)
WTVF	Nashville, TN	(CBS)
WDSU-TV	New Orleans, LA	(NBC)
WJTC	Pensacola, FL*	(ind.)
KAET	Phoenix, AZ	(PBS)
KOLO-TV	Reno, NV	(ABC)
KXTV	Sacramento, CA	(CBS)
KPBS-TV	San Diego, CA	(PBS)[a]
KPIX	San Francisco, CA	(CBS)
KSAF-TV	Santa Fe, NM	(ind.)
WAKA	Selma, AL	(CBS)
KOLR-TV	Springfield, MO	(CBS)
WTOV-TV	Steubenville, OH-Wheeling, WV	(NBC, ABC)
KAII-TV	Wailuku, HI	(NBC)
KAUZ-TV	Wichita Falls, TX	(CBS)

* Construction permit, not on air.
[a] Stereo & program-related SAP
[b] Non-program-related SAP only
[c] Program-related SAP only
[d] Adding stereo to SAP
[e] Stereo and non-program-related SAP
[f] Stereo, program and non-program SAP

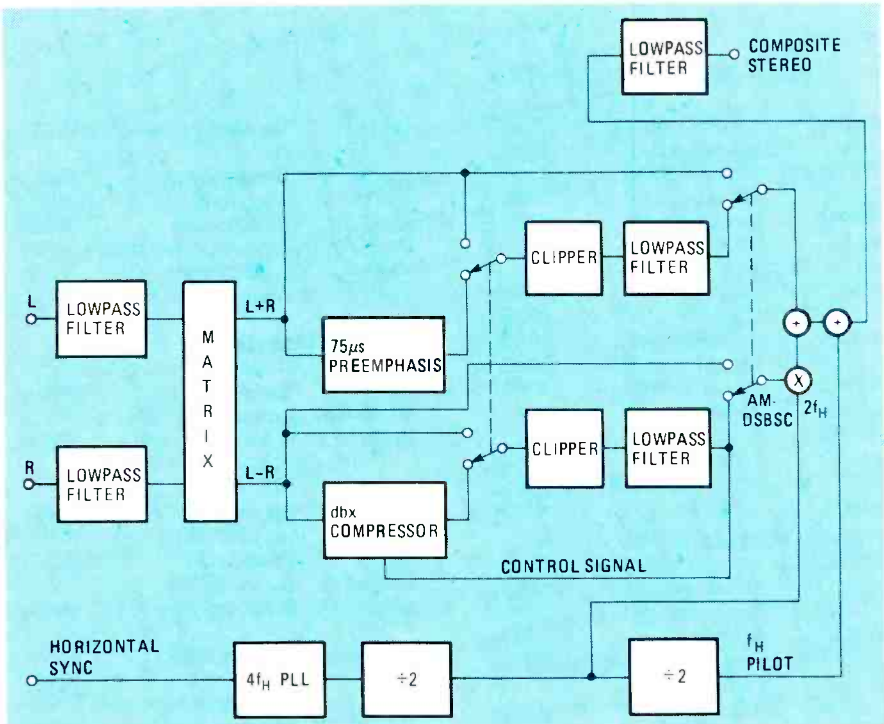


FIG. 4—STEREO GENERATOR BLOCK DIAGRAM. The composite stereo output contains L + R, L – R, and pilot signals.

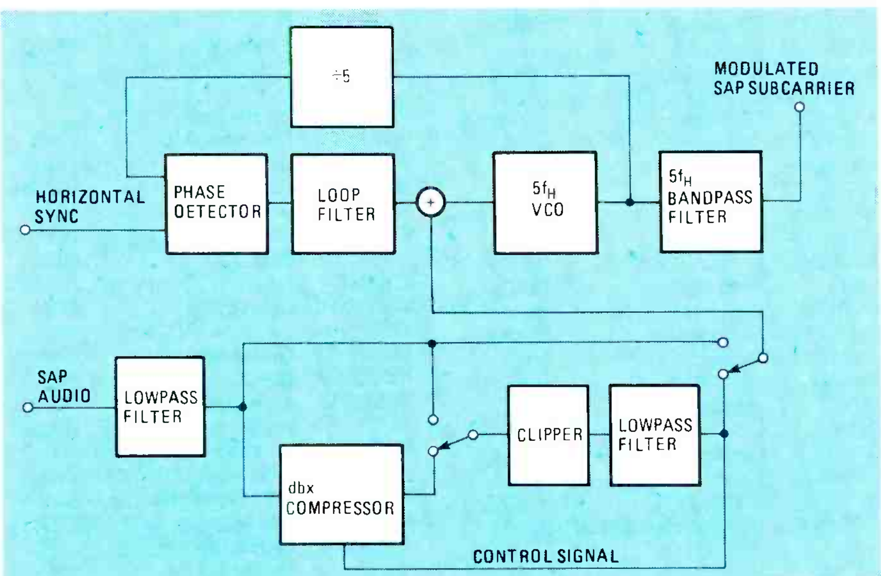


FIG. 5—SAP GENERATOR BLOCK DIAGRAM. The SAP generator can use the same compressor that is used in the stereo-signal generator.

By combining the stereo sum and difference signals in-phase and out-of-phase, the stereo decoder can reconstruct the individual left- and right-channel signals. That can be seen by the following equations:

$$(L+R)+(L-R) = 2L$$
$$(L+R)-(L-R) = 2R$$

If you're familiar with broadcast FM stereo, you've probably noticed that stereo TV uses a somewhat similar encoding method. There are some differences. The most important—which we'll describe in detail—is that the AM stereo-difference subcarrier is compressed.

A block diagram of the Zenith transmission system is shown in Fig. 3. Note that the Zenith composite signal that drives the aural (audio) transmitter is the sum of two signals—the stereo-generator and SAP-generator outputs.

The stereo generator

The input to the stereo-generator, as shown in Fig. 4, is made up of three signals: the left- and right-channel signals and the horizontal-sync signal. The L and R signals are first fed through lowpass filters to remove out-of-band components that could cause crosstalk and intermodulation. The L and R signals are then fed to a matrix circuit that forms the stereo-sum (L + R) and -difference (L – R) signals. Note that the L + R signal undergoes a 75μs preemphasis (as FM radio signals and mono TV-audio signals normally do) while the L – R signal undergoes a variable compression (the amount of compression is determined by the dbx compressor). We'll soon look at preemphasis and compression circuitry.

To prevent overmodulation and interference with other portions of the baseband (including the pilot and SAP channel), both signals are fed through clippers and lowpass filters.

Although not shown in Fig. 4, equalizers are normally included in one or both of the L + R and L – R paths. They are placed there to help ensure proper stereo separation.

Because the dbx-compressor output may contain a large amount of noise, it may be difficult to measure such things as stereo separation. To overcome that, as shown in Fig. 4, switches are provided to take the compressor and/or the clippers and lowpass filters out of the circuit.

A subcarrier at $2f_H$, twice the horizontal line frequency, is AM-DSBSC (AM double-sideband, suppressed carrier) modulated by the compressed L – R signal and is summed with the preemphasized L + R signal. The $2f_H$ subcarrier signal is also divided by two to supply the pilot tone. The composite stereo signal that is output from the stereo generator contains the stereo sum (mono) signal, the stereo difference signal, and the pilot tone.

The SAP generator

A block diagram of the other major component of the Zenith transmission system—the SAP generator—is shown in Fig. 5. The SAP audio is processed in much the same way that the stereo-difference signal is. A lowpass filter is used to remove high-frequency components that could overload the compressor, and a clipper is used to prevent overmodulation of the SAP subcarrier and thus prevent interference with the rest of the audio baseband. Equalization, which was used in the stereo generator to preserve stereo separation, is not needed here.

Note the $5f_H$ phase-locked loop in Fig. 5. The compressed audio is added to the PLL control voltage and thus frequency-modulates the VCO (voltage controlled oscillator). The frequency modulated subcarrier is then passed through a bandpass filter to protect the other audio signals from SAP spillover interference.

Now, if we look back to the block diagram of the Zenith transmission system (Fig. 3), we see that the outputs of the stereo generator and SAP generator are added together to form the composite signal, which frequency-modulates the TV audio carrier.

dbx noise reduction

As we mentioned earlier, the BTSC

system is similar to the broadcast-FM stereo system. And, just like broadcast FM, the high-frequency components of the BTSC signal contain more noise than the low-frequency components. The L − R subcarrier is, of course, at a higher frequency than the main channel, and therefore suffers from more noise.

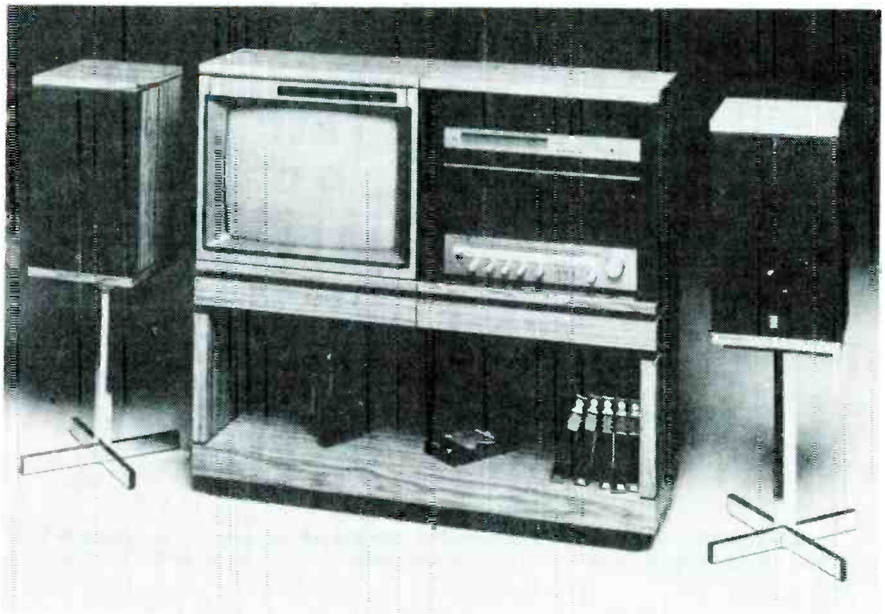
The Zenith transmission system increases the modulation level or deviation of the L − R signal to help matters somewhat, but the difference is limited to 6 dB because too much modulation will cause interference to the main channel. Even with the increased modulation of the L − R channel, the noise level of stereo reception is about 1[illegible] dB greater than mono reception *even under ideal reception conditions*.

In less-than-ideal conditions, the noise-level difference would be worse. For example, in a *grade B* reception area (where the received picture is somewhat snowy but considered acceptable by most people), the mono signal-to-noise ratio is about 65 dB—most listeners won't hear any noise. Without noise reduction, however, the stereo signal-to-noise ratio would be about 50 dB. That's 5–10 dB worse than a standard compact cassette without noise reduction! It's obvious that for stereo TV to sell its performance would have to be better than that. To get that better performance a noise-reduction system is needed that will:

- Provide noise reduction even in poor-reception areas.
- Preserve the dynamic range of the input signal without losing *headroom* (the safety margin between the maximum level and the actual level of severe overload).
- Prevent the subcarrier from interfering with transmitted power levels. (The modulation level of the composite-signal depends on the sum of the L + R and L − R signals, the modulation level of the *sum* must be limited—not just the level of the separate signals.)
- Be reliable regardless of manmade noise.
- Be reasonably inexpensive and simple to implement.

The Broadcast Systems Test Committee of the EIA felt that the dbx-TV system best met those criteria better than other systems.

We mentioned that the most important characteristic of any MTS signal is its compatibility with existing signals. Therefore, we can't do anything to the main channel. That works out fine—the noise in a multichannel system comes from the higher-frequency subcarriers. The stereo (L − R) signal, however, is encoded, as is the SAP channel. Both the stereo difference signal and the SAP signal use the same encoding scheme so that, as shown in Fig. 6, a receiver needs only a single decoder that can be switched between the two. (Keeping costs down is one way to ensure that the system will be accepted by the public!)



THIS COMPONENT-STEREO VIDEO SYSTEM from G-E can be adapted for stereo TV.

Companding

The dbx-TV system is a *companding* system: The signal is encoded or *COM*pressed before it is transmitted and then decoded or ex*PAND*ed by the receiver. Two types of compansion (or compandoring) are used by dbx: *spectral* and *wideband*. We'll get to the details shortly.

Companding (like other noise-reduction methods) works to reduce noise using the principle of *masking*: That is, if the desired signal is loud enough and has a broad enough frequency spectrum, then you will hear that signal, and not the noise of the transmission medium. You can see that principle in action yourself by recording on cassette tape—and at the same level—both a low-frequency tone and some music with a much broader spectrum (some rock-'n-roll music, for example). You will note that the recording of the rock music will have much less perceivable noise. If you record the low frequency tone at a higher level; it will appear to have less noise than the original recording of the same tone.

From the above description, we can see that for the dbx-TV system to work, it must meet two criteria. First, the level of

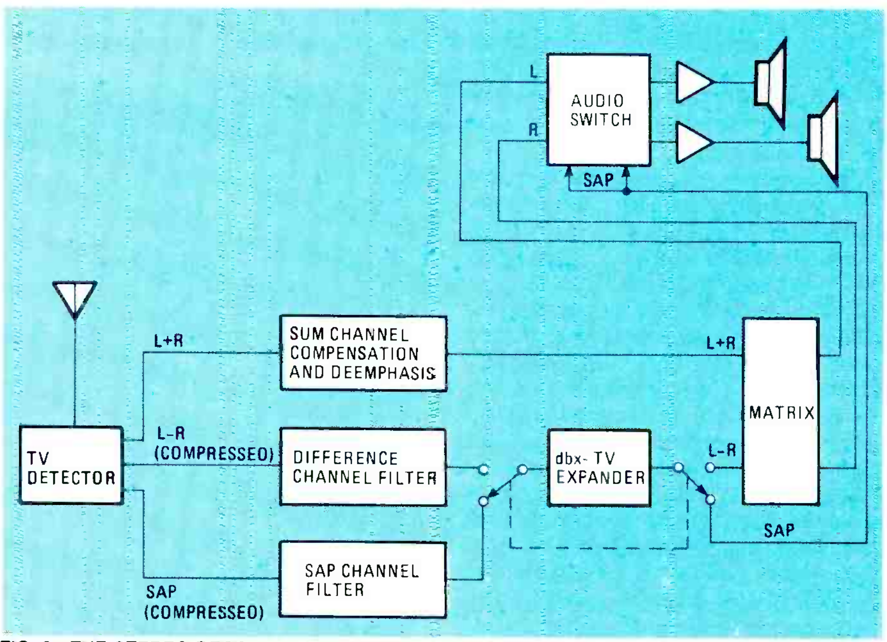


FIG. 6—THE STEREO DECODER can use the same expander for stereo and SAP decoding, and the same speakers can be used for either stereo or SAP programming. It may be desirable, however, to use a separate SAP expander and separate SAP speaker. That's because the SAP channel isn't limited to carrying second-language programming. It could carry an extra audio signal to enhance what's on the main speakers, or it could carry non-program-related material.

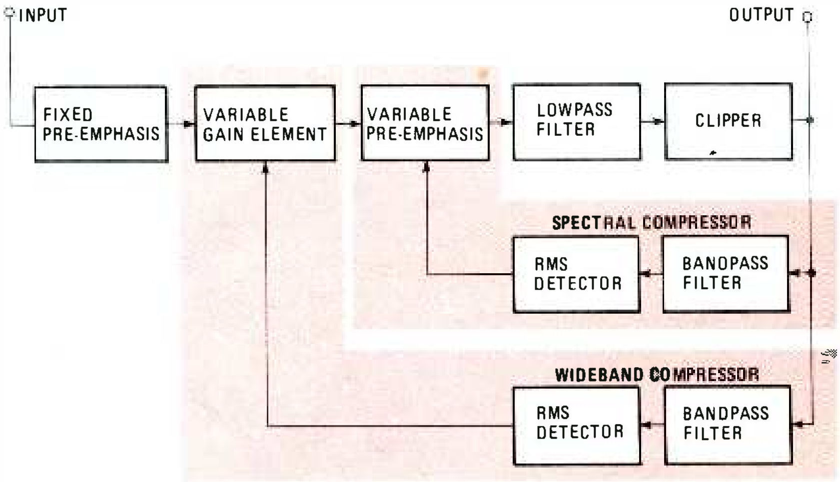


FIG. 7—BLOCK DIAGRAM of the dbx-TV compressor. Note that the compressor contains three main sections: a fixed preemphases network, a spectral compressor network, and a wideband compressor network.

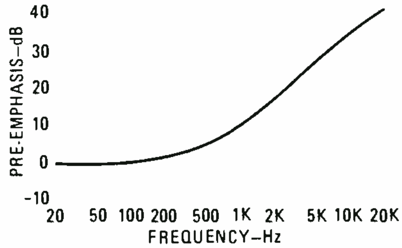


FIG. 8—FIXED PREEMPHASIS FREQUENCY RESPONSE curve shows that the combined effect of the of the 75µs and 390-µs networks helps to overcome the large amounts of noise present in poorer-reception areas.

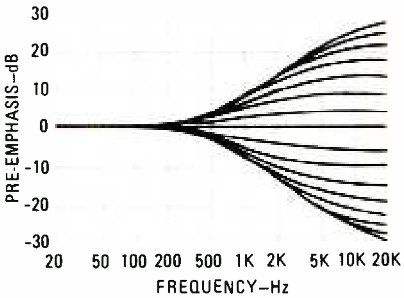


FIG. 9—SPECTRAL COMPRESSION. Here we see the range of variation in frequency-response that the spectral compressor can produce. The spectral compressor examines the input signal to determine the appropriate preemphasis or deemphasis.

the audio signal must be high when compared to the background noise. Second, the spectrum must be wide enough to mask the background noise. Another important consideration is that the companding process must not add any distortion to the desired signal. Figure 7 shows a block diagram of the dbx-TV compressor that meets those criteria. We'll cover its main sections separately.

Fixed preemphasis

Because the level of the background noise increases with frequency—by 3-dB per octave in the stereo channel of the Zenith system and 9 dB per octave in the SAP channel—masking will occur only if the spectrum of the transmitted signal contains quite a bit of high-frequency information.

Unfortunately, the energy of most program material is concentrated at relatively low frequencies, so keeping the program-signal amplitude levels high will not mask the noise sufficiently.

We can, however, change the spectrum of the audio signal so that it is more evenly balanced between highs and lows by using *preemphasis*. FM broadcasting and mono TV-audio uses a 75-microsecond preemphasis. In the dbx-TV system, two preemphasis networks are used to reduce noise and hiss in even less-than-ideal reception areas. The frequency response of the complete fixed preemphasis is shown in Fig. 8. A deemphasis network must, of course, be included in the receiver.

As you might guess, fixed preemphasis is not enough: Signals that already contain mostly high frequencies will be overmodulated, and low-level signals that contain only low frequencies will still be noisy, even with the strong preemphasis.

Spectral companding

To get around the problem of reducing noise in program signals that contain mostly high or mostly low frequencies, *spectral companding* is used. The spectral compressor examines the frequency content of the signal and varies the high-frequency preemphasis accordingly. In other words, the high-frequency preemphasis is boosted in signals that contain low frequencies. But if a signal contains mostly high frequencies, some deemphasis is provided.

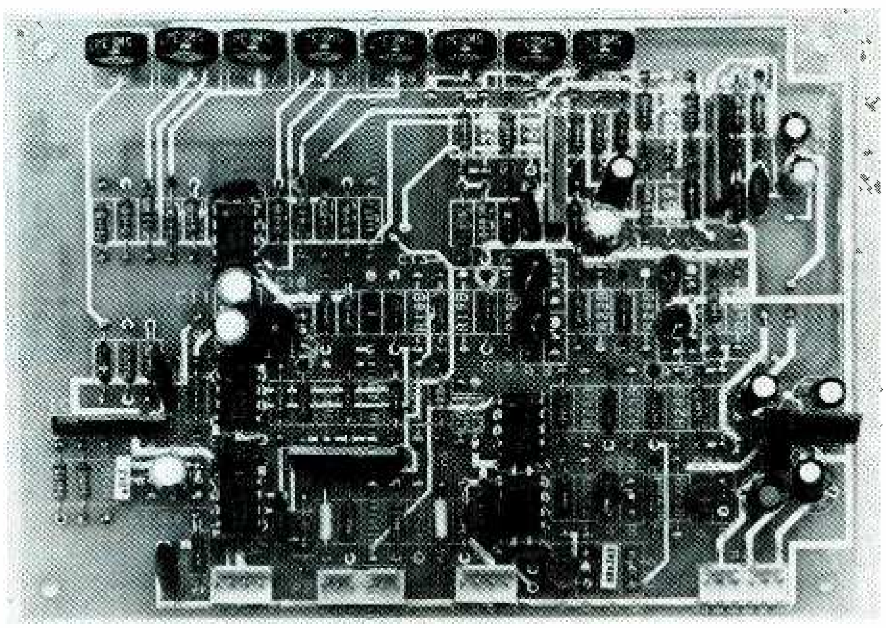
The range of the frequency response of the spectral compandor is shown in Fig 9. As you can see in the figure, that range is broad, which ensures that masking will be provided. That's because the encoded signal is dynamically adjusted so that it contains a high proportion of—but not too much—high frequencies

A spectral expander is used in the receiver to restore the program signal to its proper amplitude. It is essentially a mirror image of the compressor. Spectral companding gives us high masking regardless of the frequency content of the input signal and also helps to maintain the necessary headroom by using preemphasis only when necessary. The range of the frequency response available from the combination of the spectral compandor and fixed preemphasis is shown in Fig. 10.

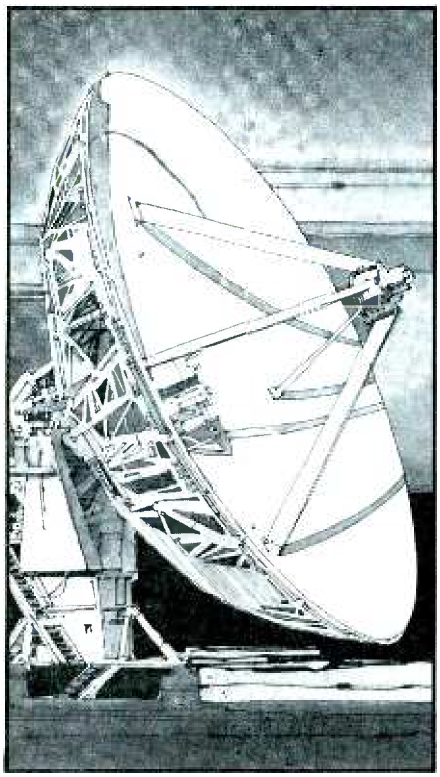
Wideband companding

Even with fixed preemphasis and spec-

continued on page 93



CIRCUIT CARDS FOR THE dbx companding system were designed to make implementation of multichannel TV sound easy for broadcasters.



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RA-07

BUILD THIS

SONIC MOTION DETECTOR

Here's a unique project that uses sound to detect motion. Use it with a burglar alarm, a door opener, or in a number of other applications.

DAVID M. BENZEL

IN THIS ARTICLE, WE'LL BE LOOKING AT A low-cost motion-detector sensor suitable for a wide variety of applications. Among other things, the project can be used to detect intruders, turn on the lights when someone enters a room, or open a door when it is approached. Presently, five of the units, controlled by a KIM computer, are being used in various rooms of the author's home as a burglar alarm system. They have been in use successfully for over a year.

Theory of operation

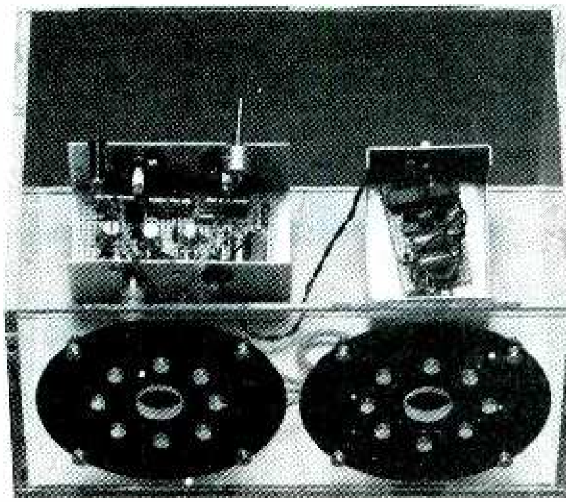
The theory behind this project is not new. In fact, the original idea for it came about while discussing police-radar fundamentals. The basic principle behind the operation of both police radar and this project is the doppler shift. Most people have observed that effect at one time or another. Remember that train whistle or car horn that sounds high pitched while coming toward you, and drops to a lower pitch as it moves away? That phenomenon is caused by the doppler shift, and the change of frequency of the sound can be expressed mathematically for reflection from a moving object as follows:

$$f_R = f_S \frac{V_M}{V_M \pm V_O}$$

where f_R is the frequency of the return wave, f_S is the frequency of the source wave, V_M is the velocity of a sound wave at 70°F at sea level and is equal to 1119 feet/second, and V_O is the velocity of the moving object.

That same formula applies to any type of wave by substituting the correct V_M; i.e. for radar using radio waves, V_M is 186,300 miles per second. The above formula simply means that if a wave of known frequency is sent out, the reflected wave will be different in frequency if the reflecting object is moving. Therefore by having a device that is able to determine if the reflected wave is different in frequency from the one sent out, moving objects in the range of the device can be detected.

The above formula provides important information for the choice of bandwidths and cutoff frequencies. The value for f_S for the project was chosen as 17 kHz because that is about where the inexpensive tweeters used start to roll off and because that frequency is inaudible, or barely audible, to most people.



Seven miles-per-hour (or ten feet-per-second) is a reasonable maximum speed for a walking person. Substituting those values in the above equation, we can find the range of return frequencies. If moving toward the source:

$$f_R = 17{,}000 \times \frac{1119}{1119-10} = 17153.9 \text{ Hz}$$

If moving away from the source:

$$f_R = 17{,}000 \times \frac{1119}{1119+10} = 16849.4 \text{ Hz}$$

The above values are used to determine several component values in the circuit. Referring to Fig. 1, a block diagram of the circuit, the high-frequency bandpass amplifiers must be able to pass frequencies from about 16.5 kHz to 17.5 kHz while attenuating all other frequencies. They must be able to pass and amplify the source and reflected frequencies, while rejecting other tones such as talking, outside noise, etc. The low-frequency amplifier must be able to pass the frequencies of 17.2 kHz – 17.0 kHz and 17 kHz – 16.8 kHz, or frequencies from 0 to 200 Hz.

The amount of audio power needed to drive the transmitter and amount of amplification needed in the receiver, were determined experimentally. Incidently, be sure to use high-frequency tweeters capable of operating at 17 kHz. Do not substitute small radio replacement-speakers, as they generally do not have the proper frequency response. The project was almost abandoned in its early stages, due to insufficient sensitivity of those small speakers.

Circuit description

The circuit operates in a fairly straightforward manner. Turning first to the receiver (see Fig. 2), the first stage is a high-Q, high-gain bandpass amplifier. It provides a voltage gain of about 100. The active-filter components were scaled to 17 kHz and bandpass characteristics suitable to pass the desired 16.5 kHz to 17.5 kHz, while maintaining high attenuation at higher and lower frequencies. Note the decoupling circuit at R2 and C1, used to ensure stability and to isolate the op-amp from any supply noise. Capacitor C2 is

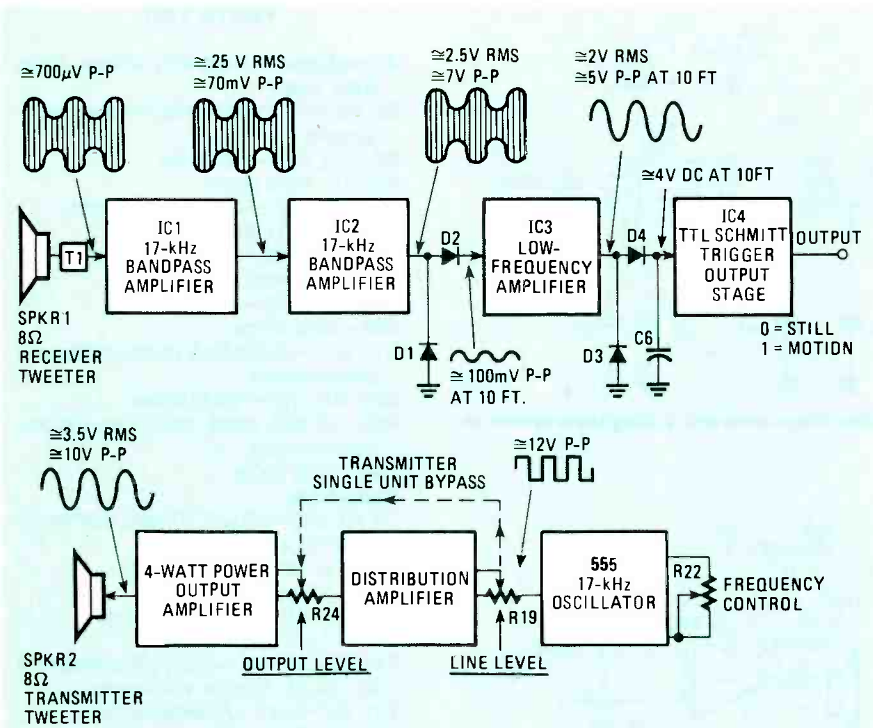


FIG. 1—BLOCK DIAGRAM of the sonic motion-detector system. Voltages given assume an object located 10 feet away.

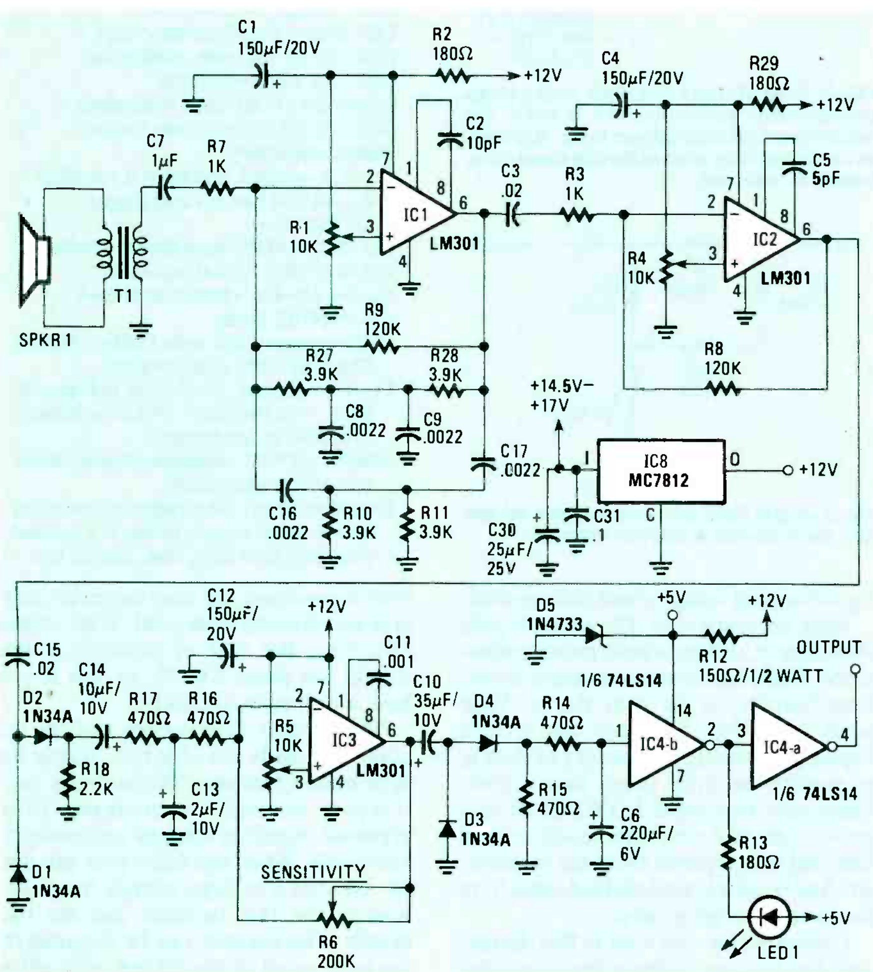


FIG. 2—A TWEETER, SPKR 1, is used as a sound-detection element by the receiver as shown in this schematic.

used to set the high-frequency rolloff characteristics of the op-amp and helps prevent IC1 from oscillating. Integrated circuit IC1 should be a fairly high-frequency op-amp; the same holds true for IC2 and IC3. If you are substituting a device other than the one specified, check the manufacturers data sheet to be sure it has sufficient gain at 17 kHz. For instance, a 741 op-amp would not work here since its gain drops to a maximum of about 40 at 17 kHz. Impedance matching and voltage step-up between the tweeter (used here as a sound detector rather than a sound source) and the first stage is done by T1 an 8-ohm/1000-ohm audio transformer. That transformer is placed in the circuit so that the 8-ohm side is connected to the speaker.

The second stage is a high-frequency amplifier with a gain of about 100. Low-frequency attenuation is provided by C3 and R3. High-frequency attenuation and stability is provided by C5. Power-supply decoupling is taken care of here by R5 and C4. The magnitude of the received 17-kHz signal at this point should be about 4 to 8 volts P-P.

If there is a moving object in the range of the device, there will be another frequency present at the output of that stage. In addition to the 17 kHz being reflected from the walls, doors and other stationary objects, there is also a weaker signal whose frequency is determined by the speed of the moving object. Those two signals (a strong 17-kHz signal and a weaker ±doppler signal) appear as an amplitude-modulated waveform. Germanium diodes D1 and D2 are used to detect that AM signal, much like a crystal radio.

The third stage is a variable-gain low-frequency bandpass amplifier that rolls off slowly below 15 Hz and above 200 Hz. Those frequencies represent the average range of doppler-shifted frequencies as determined earlier in the article. That stage uses a potentiometer, R6, to control unit sensitivity; it varies gain from 1 to about 200. The output of that stage should be about 5 volts P-P, if there is motion in the range of the device.

That AC signal is rectified by D3 and D4. The DC produced by those diodes is fed to an integrator. The integrator makes sure that motion is detected for about two-tenths of a second before setting off the Schmitt trigger (the fourth stage). That ensures that random system noise and room noise will not trip the unit. In addition, by placing C6 on the input of the TTL Schmitt trigger, the unit will always power up in the "not tripped" or still mode.

The transmitter circuit (see Fig. 3) is quite simple in operation. A 555 timer is used as an oscillator to produce the 17-kHz carrier. It is a good idea to use a polystyrene capacitor for C26 (the .01μF

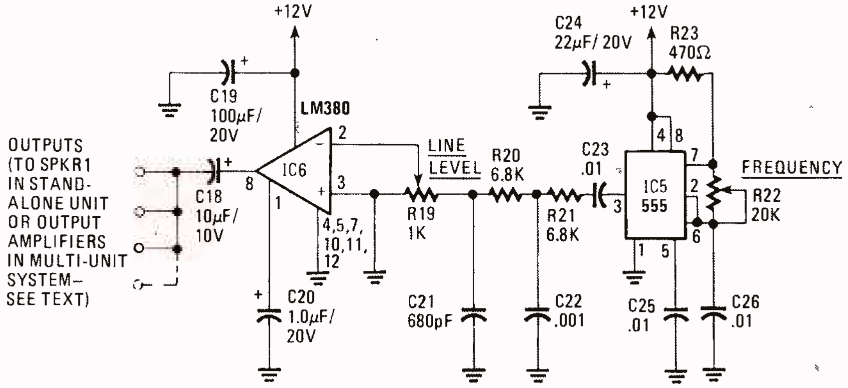


FIG. 3—THE OUTPUT OF the LM380, IC1, is used to either drive a speaker in a stand-alone system, or an output amplifier in a multi-unit system.

in the 555-oscillator timing circuit) to reduce frequency drift with temperature. The signal can take one of two paths after that depending on whether a single- or multiple-unit setup is involved.

In single-unit systems, a 555 timer and a single LM380, or other suitable audio power-amplifier, are used to drive the tweeter directly (see Fig. 3). An LM380 is a high-gain audio-power amplifier capable of producing about 3 watts of audio power. Other desirable characteristics of that amplifier are that it requires only one power supply, and its inputs are ground referenced.

In the author's set-up, which uses units in five different rooms, the LM380 shown in Fig. 3 serves as a distribution amplifier. Its output is fed to a second LM380, which serves as an output amplifier, in each unit (see Fig. 4).

The project requires 12 volts. Here, that voltage was derived by feeding 14.5–17 volts from a wall-plug supply to a 12-volt regulator housed in the receiver case.

One problem with that set-up is that the system becomes disabled if power in the house is interrupted. A solution to that problem is to supply a battery back-up as shown in Fig. 5. The circuit shown in that figure will enable B1, a battery pack made up of 10 NiCd cells in series, to cut in any time that power is interrupted. It will also trickle charge the cells so that the batteries will not become depleted during the long (hopefully!) periods between uses.

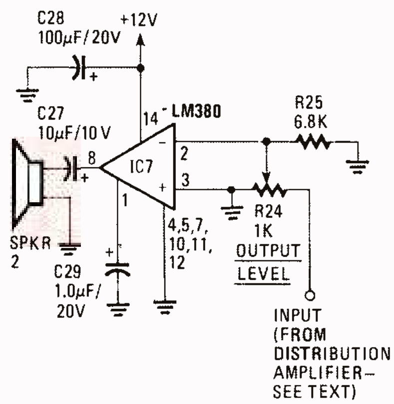


FIG. 4—IN MULTI-UNIT SYSTEMS, only a single oscillator/distribution-amplifier is used. The output from that circuit (shown in Fig. 5) is fed to an output amplifier, such as the one shown here, located in each unit.

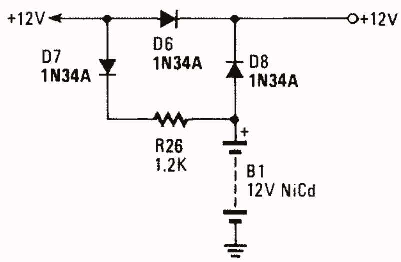


FIG. 5—A BATTERY BACK-UP will keep the system active in case of a power interruption.

Construction

Although there is little that is critical about the circuit, good construction practices should be followed. The author's prototypes were built on perforated construction board and point-to-point wiring was used with good results. Figure 6 shows the receiver and output-amp board layout used by the author. Note that R6 and LED1 are brought outside of the box housing the receiver circuit and are cemented to the cover of that box. Also ⅛-watt resistors were used in the prototype. As those resistors can be difficult to come by, we suggest using ¼-watt units instead.

Here are some tips: The ground leads should be of heavier wire to reduce inductance. Make an attempt to separate inputs from outputs on the gain stages. Keep leads short. Make absolutely sure to use a regulated, filtered power supply as shown; remember, the three stages have a combined gain of around 1,000,000. It is a good idea to house the receiver in a shielded box separate from the transmitter. And be sure to use shielded cable from the tweeter to the receiver.

Common parts are used in this design, and they are easy to obtain from a number of sources. Where performance would not be compromised, the least expensive suitable components were used. With careful shopping, the cost of building a unit should run about $35.00, or less if you have a well stocked junkbox.

The cabinet shown here and on the cover was made out of acrylic plastic for appearance reasons. The author's prototypes, however, were made from plywood, which is cheaper and easier to work with. When you make your cabinet, be sure that it is large enough to accommodate the two tweeters and the two boards. The tweeters can be mounted on the front panel of the cabinet with either

continued on page 90

PARTS LIST

All resistors ¼-watt, 10% unless otherwise noted
R1, R4, R5—10,000 ohms, trimmer potentiometer
R2, R13, R29—180 ohms
R3, R7—1000 ohms
R6—200,000 ohms, potentiometer
R8, R9—120,000 ohms
R10, R11, R27, R28—3900 ohms
R12—150 ohms, ½ watt
R14–R17, R23—470 ohms
R18—2200 ohms
R19, R24—1000 ohms, multi-turn trimmer potentiometer
R20, R21, R25—6800 ohms
R22—20,000 ohms, multi-turn trimmer potentiometer
R26—1200 ohms
Capacitors
C1, C4, C12—150 µF, 20 volts, electrolytic
C2—10 pF, ceramic disc
C3, C15—.02 µF, ceramic disc
C5—5 pF, ceramic disc
C6—220 µF, 6 volts, electrolytic
C7—0.1 µF, ceramic disc
C8, C9, C16, C17—.0022 µF, polystyrene
C10—35 µF, 10 volts, electrolytic
C11, C22—.001 µF, ceramic disc
C13—2 µF, 10 volts, electrolytic
C14, C18, C27—10 µF, 10 volts, electrolytic
C19—100 µF, 20 volts, electrolytic
C20, C29—1 µF, 20 volts, electrolytic
C21—680 pF, ceramic disc
C23, C25—.01 µF, ceramic disc
C24—22 µF, 20 volts, electrolytic
C26—.01 µF, polystyrene
C28—100 µF, 20 volts, electrolytic
C30—30 µF, 25 volts, electrolytic
Semiconductors
IC1–IC3—LM301 operational amplifier
IC4—74LS14 hex Schmitt trigger
IC5—555 timer
IC6, IC7—LM380 operational amplifier
IC8—MC7812 12-volt regulator
D1–D4, D6–D8—1N270 or 1N34A
D5—1N4733 Zener
LED1—green LED with holder (Radio-Shack 276-019 or equivalent)
T1—transformer, 1000-ohm primary, 8-ohm secondary (Radio-Shack 273-1380 or equivalent)
SPKR1, SPKR2—tweeter (Radio-Shack 40-1270 or equivalent)
Miscellaneous: Perforated construction board, metal project boxes (2), cabinet materials (see text), wire, solder, etc.

Video Entertainment

Flat Panel Color TV

A practical flat-panel color display has long been a dream. Now, thanks to a recent breakthrough, that dream has come true. Here's a look at that breakthrough, and the revolutionary TV that makes use of it.

CARL LARON, ASSOCIATE EDITOR

MOST READERS OF **RADIO-ELECTRONICS** are familiar with the first generation of flat-panel LCD-TV's that began appearing during the past year. While they represented a significant step forward in technology, they left a bit to be desired in terms of performance. Among other things, those displays suffered from blurring; images seemed to flow across the screen, leaving comet-like trails behind. Also, up to now, the displays were available in black-and-white versions only.

Those drawbacks have been eliminated, however, in a new development recently announced by Epson (23530 Hawthorne Blvd., Suite 100, Torrance, CA 90505). That development is a flat-panel, *color*, liquid-crystal display with a very fast response time. In fact, despite its lower resolution, the quality of the picture that can be produced by the Epson display is comparable to that of a CRT.

A flat-panel display

In the CRT that we are all familiar with, the picture is created by sweeping an electron beam across a phosphor-coated screen in response to a video signal. In the display developed by Epson, on the other hand, the picture is generated by rows of pixels (picture elements). Each pixel is switched on and off by a microscopic thin-film transistor. The pixels in the Epson display are not phosphors, however, but are liquid crystals.

Liquid crystals are long organic molecules with the optical properties of both liquids and solids. In the display, the liquid-crystal material is sandwiched between two polarizers whose transmission axes are orthoganal (separated by 90 degrees) to each other. When no electric field is present, the condition shown in Fig. 1-a, the liquid crystal molecules are arranged so that the one nearest the front polarizer is parallel to that polarizer's transmission axis, and the one nearest the rear polarizer is parallel to that polarizer's transmission axis. The successive layers of molecules twist gradually through the 90 degrees between the front and rear polarizers. Light that enters through the rear polarizer is twisted 90 degrees by the liquid crystal molecules and passes out the front polarizer.

But when an electric field is present, as shown in Fig. 1-b, the molecules stand on end, parallel to the electric field. Since then the light is no longer twisted, light that passes through the rear polarizer is absorbed by the front polarizer.

Before a successful liquid-crystal display could be created, some relatively difficult technical problems needed to be solved. For one thing, conventional liquid crystals, the kind used in watch and calculator displays, switch relatively slowly. (By switch, we mean change from their twisted to their untwisted orientation when an electric field is applied, and back again when it is removed.) That problem was solved through the development of a liquid-crystal that reacted faster to the presence or absence of an electric field.

Incidently, the blurring that is a common problem of earlier LCD-TV displays is caused by slow switching times; Epson's display switches fast enough to totally eliminate such blurring.

Other significant problems were the low contrast of liquid-crystal displays and the fact that most were capable of only producing dark images on a light background or light images on a dark back-

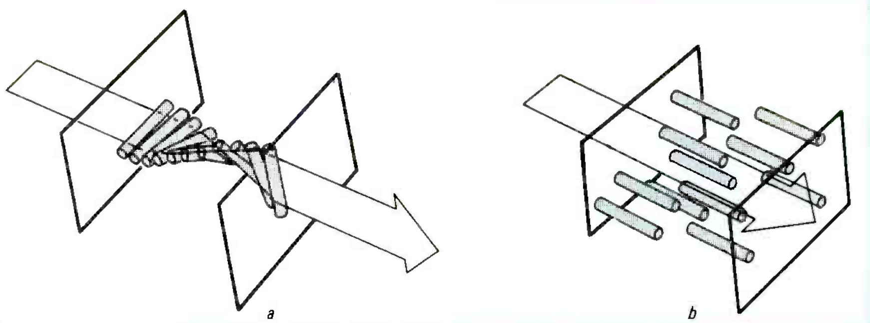


FIG. 1—WHEN NO ELECTRIC FIELD is present, the liquid-crystal molecules twist the light 90 degrees, thus allowing it to pass through the front polarizer as shown in *a*. When an electric field is applied, the molecules no longer twist the light so that the light is absorbed by the front polarizer as shown in *b*.

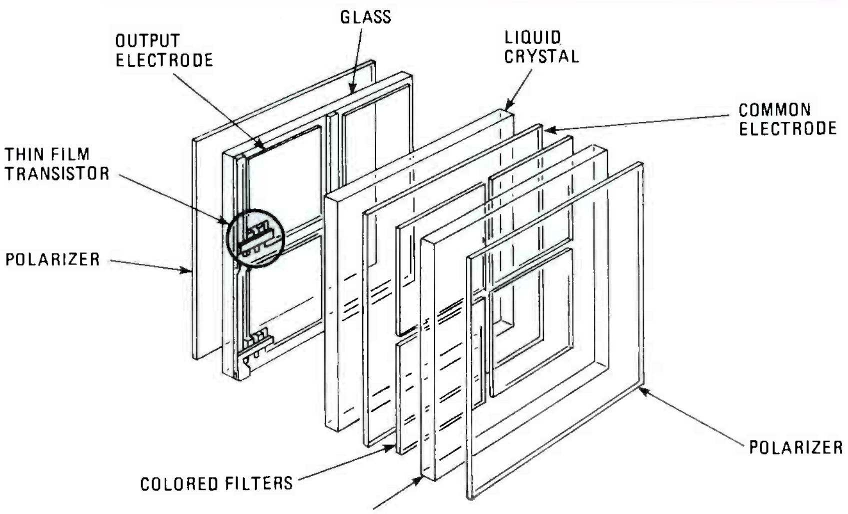


FIG. 2—THE EPSON DISPLAY consists of a rear horizontal polarizer, liquid-crystal cell, and front vertical polarizer. The electric field is applied using a unique system consisting of thin-film transistors and a common electrode.

ground. (See Fig. 1.)

The solutions

Prior to the development of Epson's display, multiplexing was used in liquid-crystal display devices to control the thousands of pixels needed to generate an image. In multiplexing, rows of electrodes are placed on one side of the liquid crystal, while columns of electrodes are placed on the other; the junctions where the rows and columns crossed would correspond to a pixel.

To turn on a pixel, control pulses would be fed in rapid succession to each row. Those pulses would turn on selected electrodes in that row. Meanwhile, all of the column electrodes would be pulsed simultaneously. While the voltage generated by the column electrodes would be insufficient to affect the liquid crystal molecules, when the column and selected-row electrodes are both pulsed, the voltage level is sufficient to effect the liquid crystal molecules and they respond.

That technique has a serious drawback—poor contrast. The reason for it is that the time-weighted average on-off voltage ratio is very low, which means that the difference between the black and white levels is not very great.

Epson's solution to that problem is a technique called "active-matrix addressing." In it, the 240 row and 220 column electrodes are all placed on a single glass substrate. On the opposite side of the display is a common electrode.

At each row and column junction, a *T*hin *F*ilm *T*ransistor (TFT) is located. Those transistors, made from polycrystalline silicon, turn on whenever a pixel is to be activated. Which pixels are to be turned on is controlled by the driver circuitry of the device. Through the use of TFT's, each pixel receives the full voltage required for turn-on. As that voltage is no longer a time-weighted average, the on-off ratio is much higher than in multiplexed devices, resulting in good contrast levels. A diagram of Epson's LCD system is shown in Fig. 2.

Adding color

Once the problem of devising a suitable monochrome display was solved, the next step was the addition of color. The approach taken was not unlike that used in conventional color CRT's. In those, the color image is created by selectively exciting red, blue, and/or green phosphors arranged in a tight matrix.

In the Epson system, color is created through the use of color filters. Tiny red, blue, and green filters are placed in a tight matrix pattern, and the entire arrangement is placed in front of the LCD. The matrix is arranged so that one of the colored filters is placed in front of each TFT (pixel).

Let's see how the system works. If, for instance, a red area is to be created, the TFT's at the blue and green filters are turned on, preventing light from passing through them. In the meantime, light continues to pass freely through the red filter. Conversely, if blue is desired, the TFT's at the red and green filters are turned on; if green is desired, the TFT's at the blue and red filters are turned on.

Colors can, of course, be combined to produce others. White is created by turning off all of the pixels in an area, thus allowing all of the colors through. Black is created by turning on all of the pixels, thus blocking all light. A full gamut of other colors and shades (see Fig. 3) can be created by selectively turning on or off the various pixels in a region.

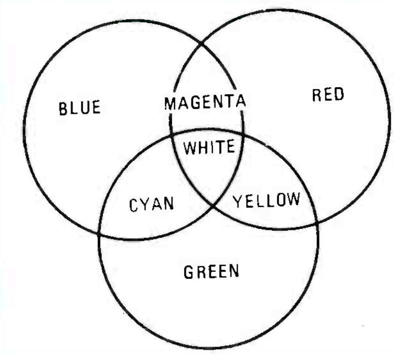


FIG. 3—A WIDE VARIETY OF COLORS and shades can be created using various combinations of red, green, and blue.

The *Elf*

Epson's first application of its new technology is its *Elf* flat-screen TV (see Fig. 4). According to the manufacturer, that tiny color TV should be on store shelves by the time you read this.

The Epson *Elf* is almost transistor-radio sized, measuring 3.15 × 6.3 × 1.22 inches, and weighs just 1.1 pounds. The set features a 2-inch, diagonal-measured screen. The heart of the device is the new flat-panel LCD unit, which is shown in Fig 5 and described above.

The tiny TV can be powered from any one of three power sources. Those are either standard or rechargable "AAA"-sized cells, an AC power adaptor, or a car-battery adaptor.

Among the user controls are TINT, COLOR, and BRIGHTNESS. All VHF and UHF TV channels can be received, and

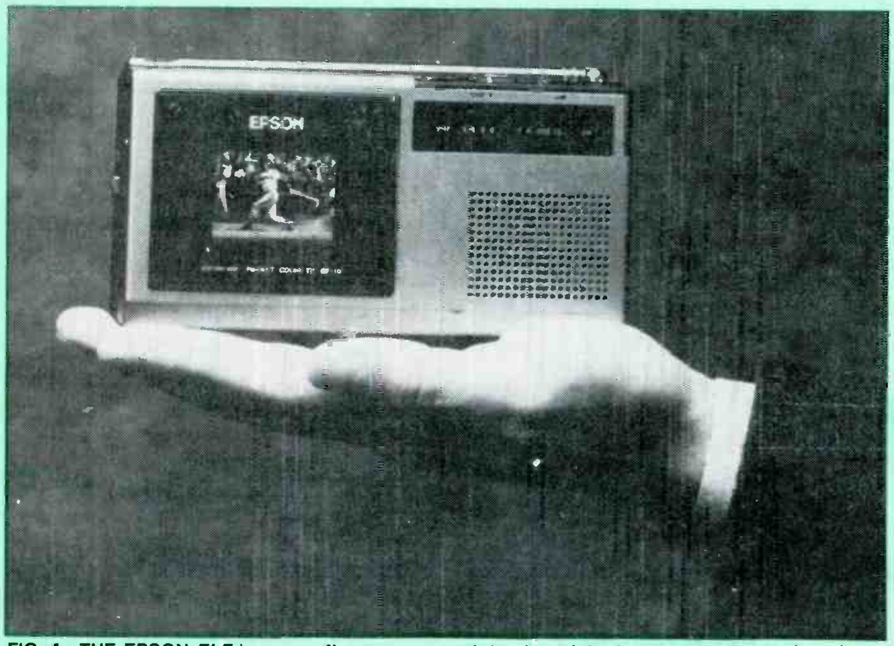


FIG. 4—THE EPSON *ELF* is as small as a paperback book, weighs just over one pound, and can operate indoors or out. It makes use of Epson's flat-screen color liquid-crystal display.

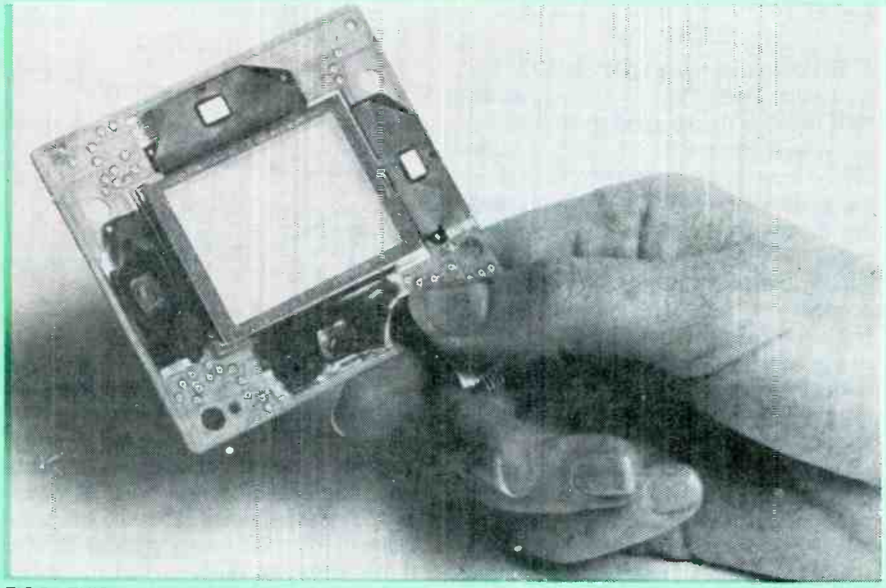


FIG 5—THIS FLAT-SCREEN color liquid-crystal display is the heart of Epson's new *Elf* pocket-sized TV.

channel selection is done via a slide-rule type tuner. There is also an earphone jack that allows the use of a standard earphone or mono headset for private viewing.

When used outdoors, conventional TV's are faced with the problem of poor contrast due to the high ambient light levels. But because the *Elf* uses a backlighted display, a unique feature turns the tables on that troublesome problem. The rear of the unit can be opened, allowing the sun's rays to be used as the light source for the backlighted LCD. That greatly improves viewing in outdoor settings. When the back is opened, a switch allows you to turn off the set's internal light source (it's no longer needed) to conserve batteries.

The *Elf* comes with a number of standard accessories. Those include an AC adaptor, mini-earphone, handstrap, soft carrying case, and a 27-inch telescopic antenna. Optional accessories include car-battery adaptor and a rechargable battery pack. There is also a fold-out tilt stand in the rear.

After spending some time with the unit, our overall impressions of it are very favorable. This set has advanced the state-of-the-art of LCD imaging manyfold. The picture produced is far better than those produced by previous LCD devices. The addition of color is also a major step forward.

In fairness, however, we must point out that the image is nowhere near as sharp as that produced by a comparable-sized CRT display. That reduced resolution is, of course, caused by the fact that far fewer pixels are used to create the image in the LCD. Even so, the image was extremely watchable. The color reproduction was true and the contrast level was acceptable for viewing even in a brightly lit office.

Other aspects of the set are pretty much what you would expect in a set of this type. Sound quality is definitely not "hi-fi," but it is adequate. The level of the audio is quite sufficient for personal listening in all but the noisiest environments. For those, you would want to use an earphone or a headset anyway. Although we tried the unit out in the "concrete canyons" of Manhattan, with all of the reception problems that that entails, the overall quality of the picture and sound was good on all receiveable VHF and UHF channels. There were a few "birdies" (spurious signals) generated by the unit when tuning between the high and low VHF bands, but those were inconsequential.

Whenever a product makes use of a technological breakthrough, you would expect the initial price to be high. The Epson *Elf* is no exception. The suggested list price of the unit at the time of this writing was $500. As with any other new technology, however, expect prices to fall as more units are sold and the costs of production go down.

The size of the display used in the *Elf* was not selected primarily because of the current popularity of small-screen personal TV's. The cost of the display is directly related to its size. Thus, although a set with a somewhat larger display (up to about 5-inches) is within the current technology, the cost of such a display would make the set too expensive to market practically at the present time.

Eventually, of course, those costs, too, will come down. Once they do, the applications for the Epson display are almost limitless. Indeed, company reasearchers are looking at a number of future products, including a flat-panel liquid-crystal TV that could be hung on a wall like a picture. While such a set is still many years away, the development of products like the *Elf* have brought it a little closer to realization. **R-E**

ALL ABOUT

CMOS CLOCK CIRCUITS

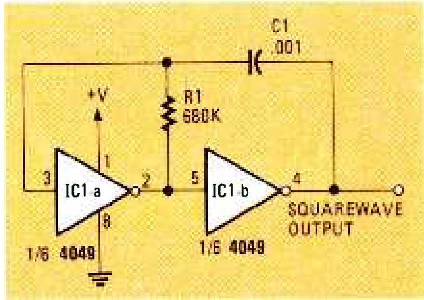


FIG. 1—THIS 2-GATE CMOS ASTABLE operates at 1 kHz with the component values shown.

The next time you need a clock generator, pick out one of these CMOS-based designs.

RAY MARSTON

CMOS LOGIC IC'S CAN EASILY BE USED TO make squarewave-generator or "clock" circuits that are both inexpensive and highly versatile. The outputs can be symmetrical or non-symmetrical, and the oscillators can be either free-running or gated. The gated oscillators can be designed to turn on with either logic-0 or logic-1 signals, and to give either a logic-0 or a logic-1 output when in the "off" mode. You can even use those "cheapo" circuits as simple VCO's (*V*oltage-*C*ontrolled *O*scillators) or as frequency-modulated oscillators.

If you want VCO operation with excellent linearity and versatility, then you have to be slightly more particular about the IC you use. We'll get to that in just a little while. But first, the basics: 2-gate CMOS squarewave-generator or astable circuits.

Two-gate astable oscillators

The simplest way to make an astable circuit is to wire two CMOS inverter stages in series and use the R-C feedback network shown in Fig. 1. That circuit generates a decent squarewave output and operates at about 1 kHz with the component values shown. The frequency is inversely proportional to the R-C time constant, so it can be raised by lowering the values of either C1 or R1. Capacitor C1 must be a non-polarized type; it can have any value from a few tens of pF to several μF. Resistor R1 can have any value from about 47 kilohms to 22 megohms. With those ranges of values, the operating frequency can vary from below 1 Hz to about 1 MHz. For variable-frequency operation, R1 should be replaced by a series combination of a fixed and a variable resistor.

The output of the astable circuit in Fig. 1 switches (when lightly loaded) almost fully between the zero and positive supply rail values. But the R1-C1 junction is prevented from swinging below zero or above the positive rail levels by on-chip clamping diodes at the input of IC1-a. That characteristic causes the operating frequency of the circuit to be somewhat dependent on the supply: Typically, the frequency falls by about 0.8% for a 10% rise in supply voltage. If the frequency is normalized with a 10-volt supply, the frequency falls by 4% at 15 volts or rises by 8% at 5 volts.

The operating frequency of the circuit shown in Fig. 1 is also influenced by the individual gates that are used. You can expect the frequency to vary by as much as 10% between individual IC's. The output symmetry of the waveform also depends on the particular IC used and, in most cases, the circuit will give a non-symmetrical output. In most "hobby" or other non-precision applications, those defects of the basic astable circuit are of little practical importance.

We should note here that for the circuit in Fig. 1—and all of the others that we'll present this month—the supply voltage indicated by "+V" can be anywhere from 3 to 18 volts DC. Also, the CMOS IC's used are all of the "B-series" type (with improved gate-oxide protection.)

Figure 2 shows an improved, "compensated" astable circuit in which R2 is wired in series with the input of IC1-a. That resistor must have a value that is large relative to R1; its main purpose is to allow the R1-C1 junction to swing freely below the zero and above the positive supply rail

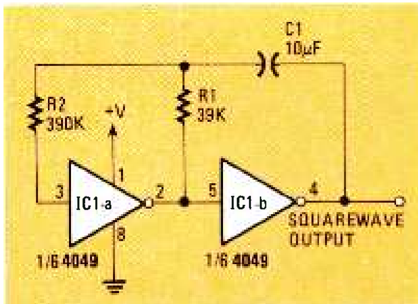


FIG. 2—THE "COMPENSATED" VERSION of the 2-gate astable oscillator has excellent frequency stability with variations in supply voltage.

voltages during circuit operation and thus improve the frequency stability of the circuit. Typically, when R2 is ten times the value of R1, the frequency varies by only 0.5% when the supply voltage is varied between 5 and 15 volts. An incidental benefit of R2 is that it gives a slight improvement in the symmetry of the output of the astable.

The basic and compensated astable circuits of Figs. 1 and 2 can be built with a good number of detail variations, as shown in Figs. 3 to 5. In the basic astable circuit, for example, C1 alternately charges and discharges via R1 and thus has a fixed symmetry. Figures 3 to 5 show how the basic circuit can be modified to give alternate charge and discharge paths for C1 and thus to allow the symmetry to be varied at will.

The circuit in Fig. 3 is useful if you need a highly non-symmetrical waveform (such as a pulse). Capacitor C1 charges in one direction via R2 in parallel with R1, to generate the *mark* (or pulse) part of the waveform. It charges in the reverse direc-

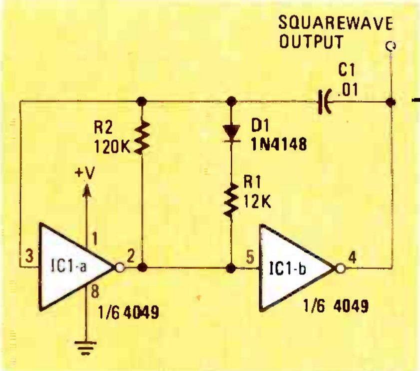


FIG. 3—YOU CAN MODIFY THE 2-gate astable to give a non-symmetrical output. The "mark" time is controlled by the parallel combination of R1 and R2. The "space" time is controlled by only R2.

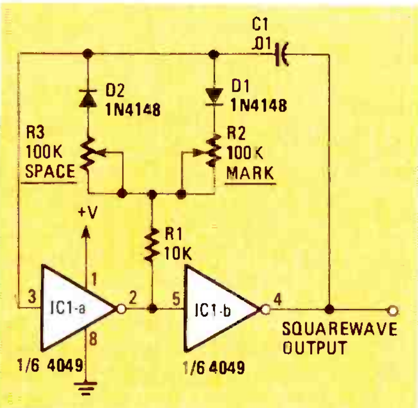


FIG. 4—THE "MARK" AND "SPACE" times can be independently varied by R2 and R3 respectively.

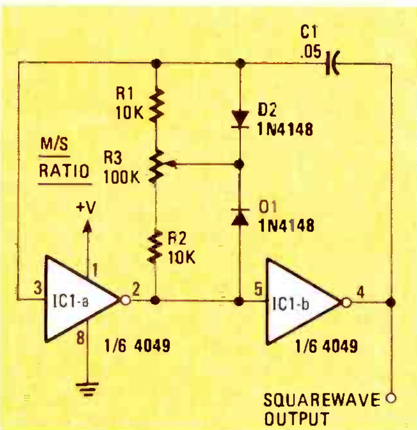


FIG. 5—THE DUTY CYCLE OF THIS ASTABLE is fully variable from 1:11 to 11:1.

tion via R2 only, to give the *space* between the pulses.

Figure 4 shows the modifications for generating a waveform with independently variable mark and space times; the mark time is controlled by R1, R2, and D1, and the space time is controlled by R1, R3, and D2.

Figure 5 shows the modifications to give a variable duty-cycle (or mark/space ratio) output while maintaining a near-constant frequency. Here, C1 charges in one direction via D2 and the lower half of R3 and R2, and in the other direction via D1 and the upper half of R3 and R1. The duty cycle can be varied over a range of 1:11 to 11:1 via R3.

Figure 6 shows a couple of ways of using the basic astable circuit as a very simple VCO. The circuit in Fig. 6-a can be used to vary the operating frequency over a limited range via an external voltage. For satisfactory operation, R2 must be at least twice as large as R1. Its actual value depends on the required frequency-shift range: A low R2 value gives a large frequency-shift range, and a larger R2 value gives a small frequency-shift range. The circuit in Fig. 6-b acts as a special-effects VCO in which the oscillator frequency rises with input voltage, but switches off completely when the input voltage falls below a value preset by R3.

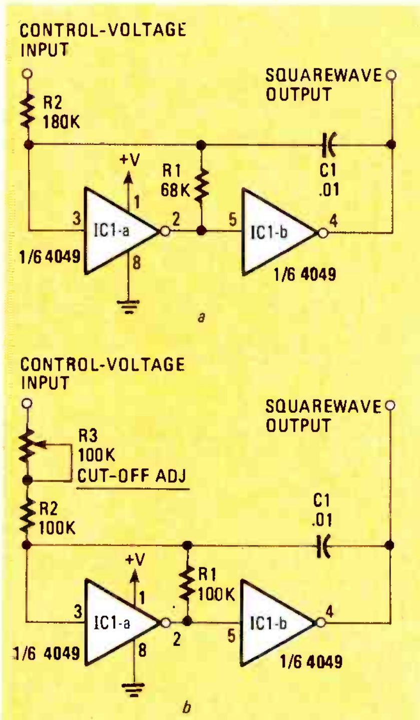


FIG. 6—A SIMPLE VOLTAGE-CONTROLLED OSCILLATOR or VCO is shown in *a*. Shown in *b* is a VCO that cuts off when V_{IN} falls below a value that is preset by R3.

Gated astable circuits

All of the astable circuits of Figs. 1 to 6 can be made using NAND or NOR gates instead of inverters. Simply replace the inverters with one of the gates as shown in Fig. 7.

Using NAND and NOR gates instead of inverters has a practical advantage—it lets you modify all of the circuits in Figs. 1–6 for gated operation. In other words, the astables can be turned on and off by external signals. All you have to do is to use a 2-input NAND (4011B) or NOR (4001B) gate in place of the inverter in the IC1-a position, and apply a control signal to one of the gate input terminals. By choosing the appropriate gate, you can control your astable by either a high or a low gate signal. That is shown by the two basic versions of the gated astable multivibrator in Figs. 8 and 9.

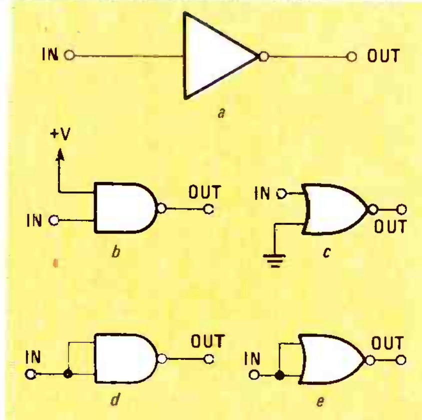


FIG. 7— TWO-INPUT NAND OR NOR gates can be used as inverters. As we'll see, they permit gated operation. As with any other CMOS IC, be sure to tie all unused inputs to one of the supply rails.

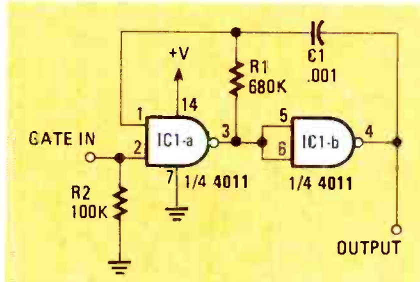


FIG. 8—THIS GATED ASTABLE has a normally-low output. It is gated on by a high input.

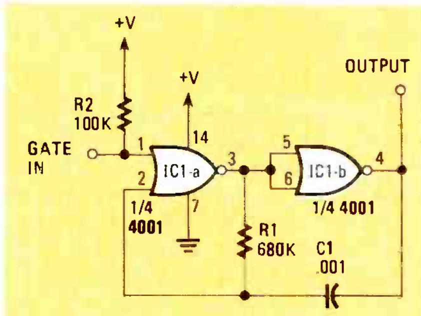


FIG. 9—THIS GATED ASTABLE has a normally-high output. It is gated on by a low input.

Note specifically from those two circuits that the NAND version is gated on by a logic-1 input and has a normally-low output, while the NOR version is gated on by a logic-0 input and has a normally high output. Pull-up (or pull-down) resistor R2 can be eliminated from the circuits if IC1-a is direct-coupled from the output of a preceding CMOS logic stage.

In the basic gated astable circuits of Figs. 8 and 9, the output signal terminates as soon as the gate drive signal is removed. Consequently, any noise present at the gate terminal also appears at the outputs of those circuits. Figures 10 and 11 show how to modify the circuits to over-

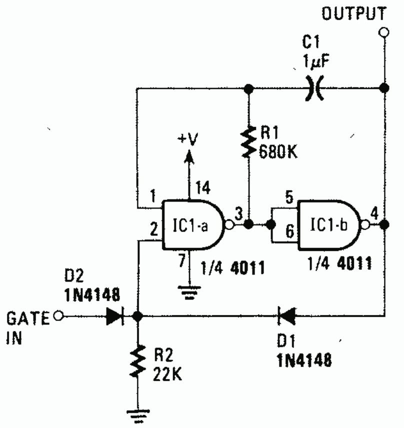


FIG. 10—SEMI-LATCHING OR "NOISELESS" gated astable has a normally-low output and is gated on by a high input.

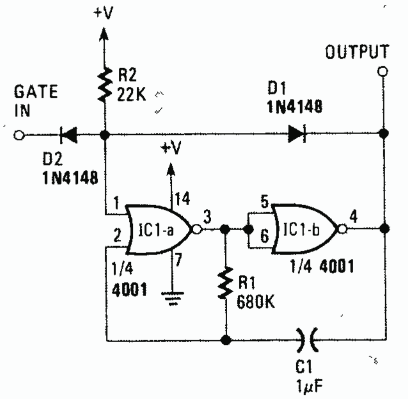


FIG. 11—ALTERNATIVE SEMI-LATCHING astable has a normally-high output and is gated on by a low input.

come that problem. There, the gate signal of IC1-a is derived from both the "outside world" and from the output of IC1-b via the diode OR gate (D1, D2, and R2). As soon as the circuit is gated from an external signal applied via D2, the output of IC1-b reinforces or self-latches the gating via D1 for the duration of one-half astable cycle. That eliminates any effects of a noisy external gate signal. The outputs of the "semi-latching" gated astable circuits are thus always complete numbers of half cycles.

Ring-of-three circuits

The 2-gate astable circuit is not generally suitable for direct use as a "clock" generator with fast-acting counting and dividing circuits. That's because it tends to pick up and amplify any supply-line noise during the "transitioning" parts of its operating cycle and to thus produce squarewaves with "glitchy" leading and trailing edges. A far better type of clock generator circuit is the *ring-of-three* astable that is shown in Fig. 12.

The Fig. 12 ring-of-three circuit is similar to the basic 2-gate astable, except that its "input" stage (IC1-a–IC1-b) acts as an ultra-high-gain non-inverting amplifier and its main timing components (R1-C1) are transposed (relative to the 2-gate astable). Because of the very high overall gain of the circuit, it produces an excellent and glitch-free squarewave output, ideal for clock-generator use.

The basic ring-of-three astable can be subjected to all the design modifications that we've already looked at for the basic 2-gate astable—it can be used in either basic or compensated form and can give either a symmetrical or non-symmetrical output, etc. The most interesting variations of the circuit occur, however, when it is used in the gated mode, since it can be gated via either the IC1-b or IC1-c stages. Figures 13 to 16 show four variations on that gating theme.

The circuits in Figs. 13 and 14 are both gated on by a logic-1 input signal, but the

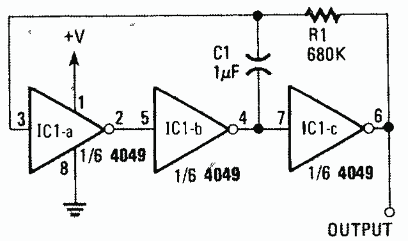


FIG. 12—THE "RING-OF-THREE" astable makes an excellent clock generator.

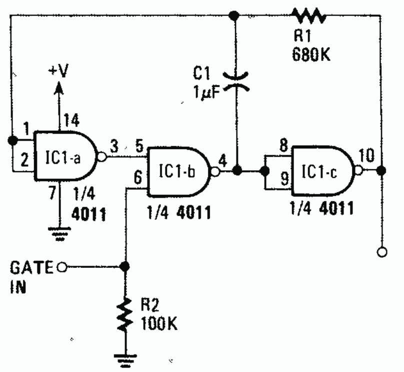


FIG. 13—THIS GATED "RING-OF-THREE" astable has a normally-low output and is gated on by a logic-1 signal.

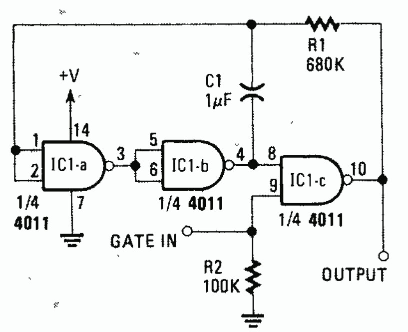


FIG. 14—THIS GATED "RING-OF-THREE" astable has a normally-high output and is gated on by a logic-1 signal.

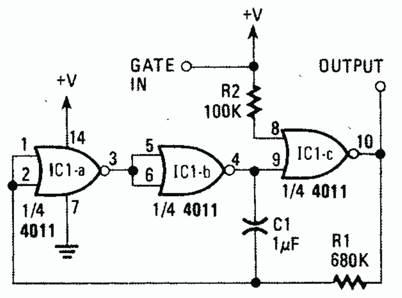


FIG. 15—THIS ASTABLE IS GATED on by a logic-0 signal and has a normally low output.

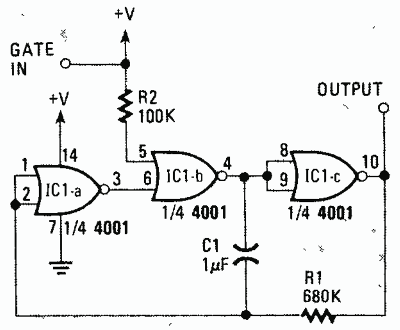


FIG. 16—THIS ASTABLE IS GATED on by a logic-0 signal and has a normally high output.

circuit in Fig. 13 has a normally-low output, while that of Fig. 14 is normally-high. Similarly, the circuits in Fig. 15 and 16 are both gated on by a logic-0 signal, but the output of the circuit in Fig. 15 is normally-low, while that of Fig. 16 is normally-high.

4046 VCO circuits

To close this look at CMOS squarewave generator circuits, let's consider some practical VCO applications of the 4046 phase-locked loop (PLL) IC. Figure 17 shows the internal block diagram and pinout of the 4046, which contains a couple of phase comparators, a VCO, a Zener diode, and a few other bits and pieces.

For our present purpose, the most important part of the chip is the VCO section. That VCO is a highly versatile device: It produces a well-shaped symmetrical squarewave output, has a top-end frequency limit in excess of 1 MHz, has a voltage-to-frequency linearity of about 1%, and can easily be "scanned" through a 1,000,000:1 range by an external voltage applied to the VCO input terminal. The frequency of the oscillator is governed by the value of a capacitor (minimum value 50 pF) connected between pins 6 and 7, by the value of a resistor (minimum value 10K) wired between pin 11 and ground, and by the voltage (any value from zero to the supply voltage) applied to VCO-input pin 9.

Figure 18 shows the simplest possible way of using the 4046 VCO as a voltage-controlled squarewave generator. In that circuit, the C1-R1 combination deter-

(continued on page 89)

VICTOR MEELDIJK

SELECTING THE BEST RESISTOR/CAPACITOR

There's much more to selecting components for your designs and projects than meets the eye. In this article, we'll look at the various types of resistors and capacitors, and what factors you should consider when selecting which type to use.

DID YOU KNOW THAT:

Polystyrene foil capacitors may be better for timing circuits than polycarbonate types?

Tantalum capacitors are not recommended for any application where current spikes are present?

A hybrid potentiometer consisting of a wirewound element and a conductive plastic track will have a life span that is 10 times greater than that of a wirewound potentiometer?

Power wirewound resistors can be operated with a body temperature of 275°C, and that some can operated at body temperatures of as high as 500°C?

From the above, it should be clear that there's a lot to know about the many different types of resistors and capacitors available. That's because each type has its own unique characteristics, and those characteristics make some types of resistors and capacitors far better for certain applications than others. Selecting the proper component for a particular application is vital in order to ensure the reliability of your design. In this article, we'll look at the various factors that you should consider when selecting resistors and capacitors for your projects.

Resistors

When selecting a resistor, consider stability, noise, power dissipation, environment, AC requirements, and resistance. Actual resistance value is a function of tolerance, voltage coefficient, temperature coefficient, and drift with time. The power rating is based upon ambient temperature and derating. Derating, which is the operation of a component at something less than 100% of its specified rating, may be necessary because of environmental conditions.

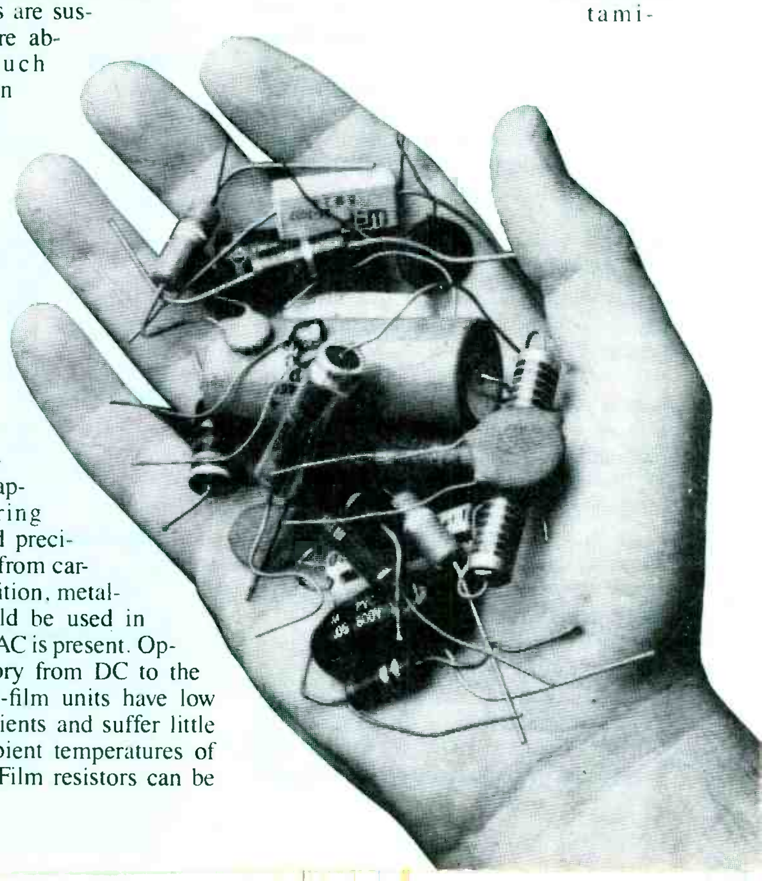
Resistor compositions include carbon, film, and wirewound for fixed resistance units, and cermet and conductive plastic for variable resistors. Figure 1 shows many of the types of resistors available.

Carbon resistors

Carbon-composition units have a resistive element that is molded from carbon powder that has been mixed with a phenolic binder to from a uniform resistive body. That device, molded with end leads, is a general purpose resistor capable of withstanding temperature and electrical transient shocks. The carbon-composition resistor is used in applications where initial tolerance need not be closer than ±5% with long term stability no better than ±20%.

For variable resistors, one problem is that the carbon element requires a high contact force to ensure that any variation in the contact resistance remains within acceptable limits. That results in high shaft-torque and poor adjustability.

Carbon elements are susceptible to moisture absorption and such moisture absorption can cause the resistance to change by as much as 20%. That resistance shift can be reversed if the device is baked at high temperatures (100°C).



Film resistors

Metal-film devices are used in applications requiring higher stability and precision than available from carbon devices. In addition, metal-film resistors should be used in applications where AC is present. Operation is satisfactory from DC to the MHz range. Metal-film units have low temperature coefficients and suffer little degradation to ambient temperatures of 125°C and higher. Film resistors can be classified according to the techniques used in their manufacture.

One such technique is vacuum deposition, which is also known as evaporated metal film. In it, a nickel-chromium alloy is superheated in a vacuum. The alloy vaporizes and is deposited on a ceramic substrate. Small quantities of contami-

FIG. 1—THERE ARE MANY DIFFERENT resistor compositions and types. Among them are carbon, film, wirewound, cermet, and conductive plastic.

nants, called dopants, are used to control resistor characteristics such as resistance range. Those resistors are used in applications that require an extreme degree of precision.

In sputtering, a nichrome target is heated and bombarded by argon atoms. That results in metal atoms being knocked off and deposited on a substrate. Resistors manufactured using that sputtering technique are also suitable for applications that require a high degree of precision.

In metal-oxide deposition, a chemical vapor is used to deposit a tin-oxide film onto a glass substrate. That technique, which is primarily used by Corning is used to produce resistors for general-purpose, semi-precision, and precision applications.

Thin-film resistors are highly stable, have low-noise characteristics, and have a very low temperature-coefficient. They are used in digital multimeters, precision voltage-dividers, attenuators, A/D and D/A circuits, and in current-summing applications.

Typical thin-film resistors are sputtered tantalum nitride, deposited chromium cobalt, or nichrome, on a substrate. Substrates of alumina, sapphire, glass, quartz, beryllia or silicon are used.

Thin-film resistor networks are also available; those are housed in DIP's and SIP's (*S*ingle *I*nline *P*ackage).

In individual resistors, the terminals used may be either surface or wrap-around types. Wrap-around terminals wrap around the side of the substrate allowing connections to the underside. Terminals of solder, silver over nickel, platinum, or platinum gold are available. Trimming of the resistor is done either mechanically or by using a laser.

In thick-film resistors, a ceramic substrate is coated (silk screened—a mechanized stenciling process) with a glass-metal material and then fired (to cure it) at a high temperature. The glass-metal materials include nichrome, silver palladium, platinum, ruthenium, rhodium, gold and a tantalum-modified tin oxide. That film is up to 100 times thicker than evaporated or sputtered metal film (greater than .0001 inches thick) and is used in applications requiring high power density or the capability of surviving power spikes or overloads. Those units are suitable for some precision applications, but not those requiring an extremely high degree of precision.

Bulk metal resistors, made in a process that is properietary to the Vishay Corporation, metal foil is laminated to a substrate and then chemically etched to produce a conductive path. The flat element is used exclusively for high-precision applications and has tight tolerances and an excellent temperature coefficient.

TABLE 1—RESISTOR SELECTION GUIDELINES

TYPE	SPECIFICATIONS AND NOTES
Carbon composition	**Resistance range:** 2.7 ohms to 100 megohms **Power rating:** to 2 watts **Tolerance:** 5% to 20% **Temperature coefficient:** −200 to −8000 PPM/°C **Noise:** less than 6 μV/V **Derating factors:** 50% power, 80% voltage **Notes:** General purpose. Excellent transient and surge handling capabilities. RF produces capacitive effects end to end, and operation at VHF or higher frequencies reduces effective resistance due to dielectric losses. Resistance increases by 20% during storage under humid conditions.
Carbon composition potentiometer	**Resistance range:** 50 ohms to 10 megohms **Power rating:** to 5 watts **Temperature coefficient:** 1000 PPM/°C **Derating factors:** 50% power, 80% voltage **Life expectancy:** 5,000,000 rotations **Failure mode:** noise **Notes:** High shaft torque causes poor adjustability
Carbon Film	**Resistance range:** 10 ohms to 25 megohms **Power rating:** 0.1 to 10 watts **Tolerance:** 2% to 10% **Temperature coefficient:** −200 to −1000 PPM/°C **Noise:** less than 10 μV/V **Derating factors:** 50% power, 80% voltage **Notes:** General purpose, cost less than carbon-composition units
Metal film	**Resistance range:** 10 ohms to 3 megohms (high voltage types: 1 kilohm to 30 gigohms) **Power rating:** to 10 watts (high voltage types: to 6 watts) **Tolerance:** 0.1% to 2% **Temperature coefficient:** ±25 to ±175 PPM/°C **Noise:** less than 0.1 μV/V **Life expectancy** (potentiometers): 100,000 rotations **Failure mode:** resistance change or catastrophic failure **Derating factors:** 50% power, 80% voltage **Notes:** Fair degree of precision in lower value units. High stability, long life, and excellent high-frequency performance. Resistance values stable to about 100 MHz; begin to decrease beyond that frequency. Used in high-frequency tuning circuits, measuring circuits, filters, etc.
Film networks	**Resistance range:** 10 ohms to 33 megohms **Power rating:** to 0.2 watts per element, to 1.6 watts per network **Tolerance:** 0.1% to 5% **Operating temperature range:** −55 to +125°C **Temperature coefficient:** ±25 to ±300 PPM/°C **Notes:** Tracking between resistors 5 PPM/°C
Chip resistors	**Resistance range:** 1 ohm to 100 megohms **Power rating:** to 2 watts **Tolerance:** 1% to 20% **Operating temperature range:** −55 to +125°C
Power wirewound	**Resistance range:** 0.1 ohm to 180 kilohms **Power rating:** to greater than 225 watts **Tolerance:** 5% to 10% **Temperature coefficient:** less than ±260 PPM/°C **Noise:** low static, high dynamic noise levels **Derating factors:** 50% power, 80% voltage

Carbon-film resistors were introduced to perform the same basic functions as carbon-composition resistors, but at a lower price. Just like composition types, they lack the ability to withstand transient voltage spikes and have a poor temperature coefficient.

An axial-lead, carbon-film resistor is made by screening carbon based resistive inks on a ceramic rod and then firing the assembly. Alternate techniques include depositing pure carbon by cracking a hydrocarbon gas or by depositing a nickel film for resistor values of less than 10 ohms. The resistive element may also be sprayed on, applied with a transfer wheel, or dipped on.

The rod is then cut to size, leaded end caps are attached, and the unit is trimmed to a precise value. The resistor is then coated with an insulating material. Carbon-film resistors are available in the same resistance values as carbon-composition units and have a typical tolerance of ±5%.

Wirewound resistors

Wirewound resistors are used where large power dissipation is required and where AC performance is relatively unimportant. Those devices are generally satisfactory for use at frequencies up to 20kHz. They are available with various insulating/moisture preventative coatings such as vitreous enamel, cement, molded phenolic, glass sleeves, or silicone.

Vitreous enamel units have excellent moisture-resistance properties and will not burn (although they may melt) under high overload conditions since they are made from a glass type material.

Silicone, which also has excellent moisture-resistance characteristics, is an organic material and is more flammable at lower overload conditions than vitreous enamel. It will also emit gases under overload conditions leaving deposits on electrical contacts.

Cement coatings are composed of inorganic materials. Those coatings are essentially flameproof but can be made to burn if subjected to high overloads for long periods. Resistors coated with that material are also subject to changes in value with exposure to moisture.

Aluminum and water-cooled housings are also available. Those housings facilitate the transfer of heat away from the resistive element.

In wirewound resistors, three alloys are commonly used for the resistive element. They are nickel-chromium, Copper-nickel, and gold-platinum. Nickel-chromium is the most common due to its excellent temperature coefficient (less than ±5 PPM/°C) and its availability in many different diameters. Copper-nickel is the next most popular, with a temperature coefficient of ±20 PPM/°C. The gold-platinum alloy, that is actually a complex alloy of gold, platinum with small amounts of copper and silver has a high temperature coefficient of ±650 PPM/°C, but has low resistance. That resistance is 85 ohms/cmf (cmf is a circular mil foot, a hypothetical quantity equivalent to one foot of wire that is .001 inches in diameter) while nickel-chromium has a resistivity of 800 ohms/cmf. The gold-platinum alloy can also withstand harsh environments.

The ceramic core of a wirewound resistor is either beryllium oxide, which has a high cooling capability, alumina (aluminum oxide) or steatite, which has the lowest thermal conductivity of the three materials but is low cost. Figure 2 shows some steatite cores.

Wirewound resistors are most often used in voltage divider circuits, as power-supply bleeder resistors, or as series dropping resistors. Variable devices are used where voltage and current variations are expected, such as motor-speed and heater controls. Precision variable types are used in servo systems requiring precise electrical and mechanical performance.

Other resistor types

For low resistance/high current applications, edgewound ribbon type power

TABLE 1 CONTINUED

TYPE	SPECIFICATIONS AND NOTES
Precision wirewound	**Resistance range:** 0.1 ohm to 800 kilohms **Power rating:** to 15 watts **Tolerance:** .01% to 1% **Temperature coefficient:** varies with resistance **Noise:** low static, high dynamic noise levels **Life expectancy (potentiometers):** 200,000 to 1,000,000 rotations **Failure mode:** Catastrophic failure **Derating factors:** 50% power, 80% voltage **Notes:** Wirewound resistors are used in low-tolerance, high-power dissipation applications where AC performance is not critical. Power dissipation depends on heat sink or air flow around the device. When mounting on a PC board, standoffs should be used to prevent charring the board. Not suitable for use at frequencies above 50 kHz. Wirewound potentiometers do not suffer from contact resistance variations. The units can be manufactured with low temperature coefficients and tight tolerances. Applications include motor speed controls, lamp dimmers, heater controls, etc. Precision types are used in servo mechanisms.
Cermet	**Resistance range:** 50 ohms to 5 megohms **Power rating:** to 2 watts **Life expectancy (potentiometers):** 50 to 500,000 rotations **Failure mode:** noise **Derating factors:** 50% power, 80% voltage **Notes:** Very stable under humid conditions. Low temperature coefficients. Low end resistance (2 ohms). Short life expectancy. High resolution of the resistive element allows for more precise trimmer settings. Less reactance in high-frequency applications than wirewound units, and are lower in price. Cermet is also the thick film used in resistor networks and chip resistors.
Conductive plastic potentiometers	**Resistance range:** 150 ohms to 5 megohms **Power rating:** to 1 watt **Temperature coefficient:** −600 to −300 PPM/°C **Life expectancy:** 100,000 to 4,000,000 rotations **Failure mode:** Noise **Derating factors:** 50% power, 80% voltage
General purpose conductive plastic potentiometers	**Resistance range:** 1 ohm to 15 kilohms, depending on power rating **Power rating:** to 1000 watts
Precision conductive plastic potentiometer	**Resistance range:** 100 ohms to 500 kilohms **Power rating:** to 7 watts **Tolerance:** 3% **Temperature coefficients:** less than 70 PPM/°C **Life expectancy:** Greater than 2,000,000 rotations
Conductive plastic trimmers	**Resistance range:** 10 ohms to 100,000 ohms **Power rating:** to 1 watt **Notes:** Conductive plastic potentiometers have a long life expectancy and low-noise characteristics. Resistance will shift if exposed to humidity.
Hybrid potentiometers	**Resistance range:** 200 ohms to 250,000 ohms **Power rating:** to 7 watts **Tolerance:** 5% **Temperature coefficient:** less than ±100 PPM/°C **Life expectancy:** 10,000,000 rotations

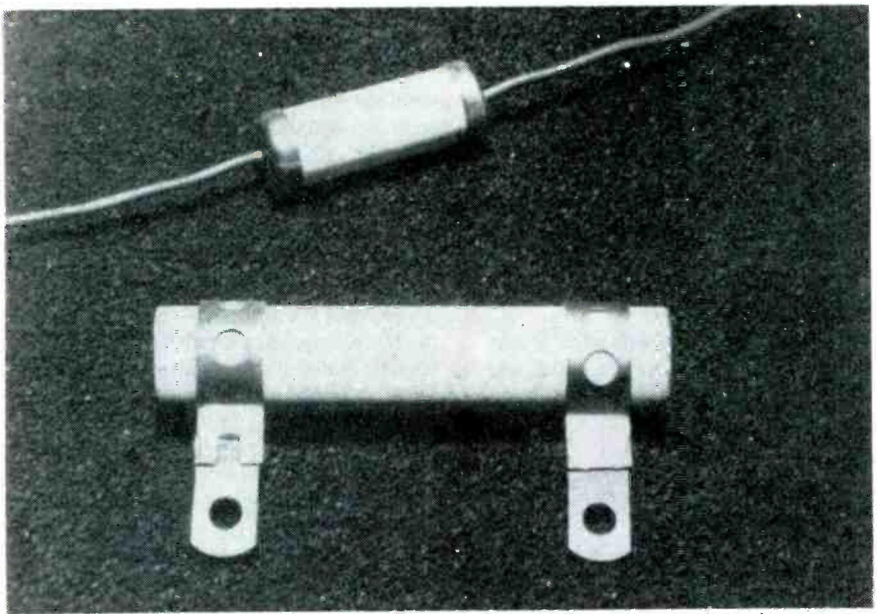


FIG. 2—MANY WIREWOUND RESISTORS use steatite cores, such as the ones shown here.

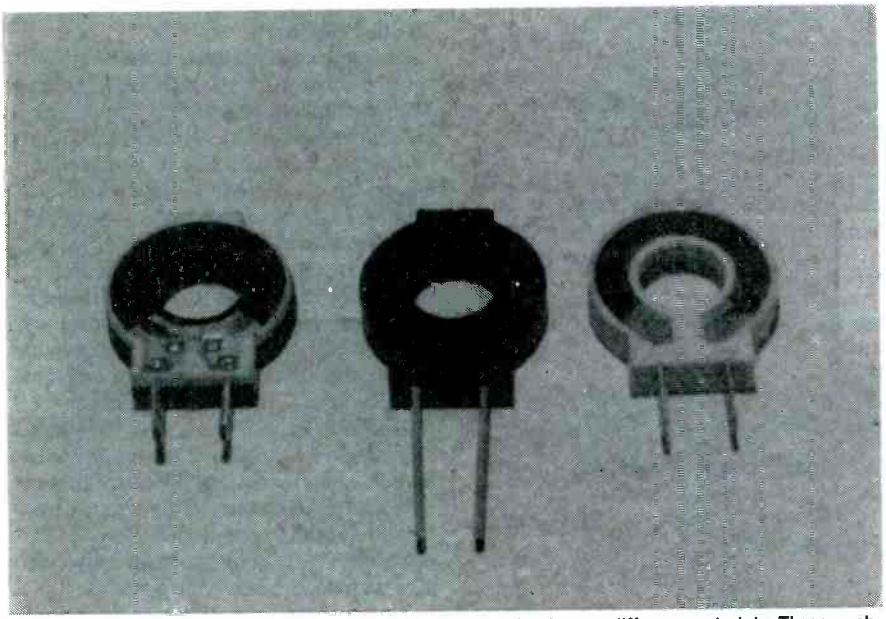


FIG. 3—POTENTIOMETERS can use resistive elements made of many different materials. Three such materials, shown above from left to right, are cermet, carbon, and conductive plastic.

resistors are available. Designed for power handling up to 1000 watts (at currents up to 100 amps) these devices are made up of steel ribbons wound into a coil and supported by ceramic insulators. They are generally rated for normal operation with a temperature rise of 375°C. Those units are used in power-supply testing and in motor-braking systems. (You may have seen them underneath subway cars, especially the older trains in New York City.)

Cermet devices have a resistive element made by combining very fine particles of ceramic, or glass, with precious metals. Cermet devices are very stable under humid conditions and have low temperature coefficients of ±100 PPM/°C. Conductive-plastic or hot-molded carbon potentiometers, for example, have an average temperature coefficient of ±1000 PPM/°C. In variable resistors, however, the cermet element is abrasive and long periods of rotational cycling will wear out the wiper long before similar use would wear out the wiper in resistive-film or conductive-plastic units. Cermet potentiometers are available in low resistance values, which makes them useful in many audio applications.

Cermet is also the thick film used in resistor networks and in chip resistors.

Conductive plastic potentiometers have a resistive element consisting of a blend of resin (epoxy, polyester, phenolics, or polyamides) and a carbon powder applied to a plastic or ceramic substrate. The plastic substrate results in a better temperature coefficient due to greater compatability between the ink and the substrate. Those devices have a long rotational life and excellent contact resistance variation, or low noise. End resistance is low, two ohms maximum.

Conductive plastic units are suitable for use in applications that require a consistent temperature coefficient over a limited temperature range, such as −25°C to 75°C. Temperature coefficient values of −200 PPM/°C may be attained by special processing of the carbon material or by incorporating metal powders, or flakes, into the element. Nickel, silver, and copper are frequently used in low-resistance devices. Conductive-plastic elements, like carbon units, vary in resistance when exposed to humid conditions. Figure 3 shows cermet, carbon, and conductive plastic units.

Hybrid potentiometers are wirewound units with a conductive-plastic track deposited along the contact path of the resistive element. That results in a device that has a better resolution and a longer life, by a factor of 10, over wirewound types. Compared to conductive-plastic units, hybrid devices have a higher power handling capability, due to the wirewound element. Like wirewound units however, they have stray capacitance at higher frequencies and have high contact resistance and marginal output smoothness when drawing current through the wiper contact.

Table 1 summarizes the resistor types available, their characteristics, recommended applications, and suggested derating factor. Use of a derating factor is an effective means to decrease the failure rate of most devices since device life is stress and temperature dependent. Derating is accomplished by either decreasing part stresses such as power/voltage or current or by selecting a higher rated part. Optimum derating occurs at or below the point where an increase in stress or operating temperature results in a large increase in the device failure rate.

One note about Table 1: The values and rating shown are provided as guidelines. While they apply to the most commonly found units, it is not impossible to find units with slightly, or greatly, different specifications.

While that concludes our look at resistors, our look at component selection is far from over. In the folowing part of this article, we'll turn our attention to the factors that should be considered when selecting capacitors.

TABLE 2—CAPACITOR SELECTION GUIDELINES

CERAMIC
Values: 1 pF to 2.2 μF
Tolerance: 10% or 20%
Voltage rating: 3.3 volts to 6 kilovolts DC
Dissipation factor: to 5%
Temperature coefficient: to 200,000 PPM/°C
For NPO's—
Tolerance: .25% to 10%
Temperature coefficient: 0 ± 30 and 0 ± 60 PPM/°C
Notes: General purpose high insulation-resistance devices used for transient decoupling of IC's and compensation of reactive changes caused by temperature variations. Applications include filtering, bypass, and non-critical coupling in high frequency circuits. Frequency sensitive (capacitance will vary with frequency) so characteristics should be measured at intended operating frequency. Should be mounted next to components being compensated, and shielded from sources of heat. Due to low voltage failure problems, should not be operated significantly under rated voltage under humid conditions. In circuit design, considerations should be given to changes in the dielectric constant caused by temperature, electric field intensity, and shelf aging.

CERAMIC CHIPS
Values: 10 pF to .18 μF
Tolerance: 5 to 20%
Temperature range: −55 to +125°C
Insulation resistance: greater than 100,000 megohms

MICA
Values: 1 pF to .1 μF
Voltage ratings: 100 to 2500 volts DC
Temperature range: −55 to +150°C
Temperature coefficient: −20 to +100 and 0 to +70 PPM/°C
Derating factor: 60% voltage (dipped case) and 40% voltage (molded case)
Mica chips—
Values: 1 to 10,000 pF
Voltage rating: to 500 volts
Notes: Used in timing, oscillator, tuned circuits, and where precise high frequency filtering is required. Capacitance and impedence limits are very stable and capacitors perform very well at frequencies of 10 kHz to 500 MHz. Devices using silver in their construction are very susceptable to silver ion migration resulting in short circuits. Failures can occur in a few hours if capacitors are exposed to DC voltage stresses, humidity, and high temperature.

GLASS
Values: .5 to 10,000 pF
Tolerance: to 5%
Voltage rating: 100 to 500 volts DC
Temperature range: −55°C to +125°C
Temperature coefficient: 0 to 140 PPM/°C
Notes: High insulation resistance, low dielectric absorption and fixed temperature coefficient. Has much higher Q than mica devices. Performs very well at high frequencies up to 500 MHz and can operate in range of 100 kHz to 1 GHz. Capable of withstanding severe environmental conditions but are susceptable to mild mechanical shocks and should be mounted accordingly.

PAPER/PLASTIC DIELECTRICS
Many dielectric and case configurations are available. Each type has its own characteristics. For example, metalized paper units have low insulation resistance and are prone to dielectric breakdown failures. Plastic types have superior moisture characteristics than paper units. Polycarbonate and Mylar types are used in applications that require minimum capacitance change with temperature, such as tuned or timing circuits.
Metalized polycarbonate and polycarbonate film—
Values: up to 50 μF
Voltage rating: to 1000 WVDC
Dissipation factor: .5% (at 25°C and 120 Hz)
Temperature range: −55 to +125°C
Derating factors: 50% voltage; 80% of rated temperature
Notes: DC blocking, filter, bypass, coupling, and transient supression applications. Close tolerance, high frequency capability (40–400 kHz) and high insulation resistance. Not suitable for sample/hold circuits, fast settling amplifiers, or filters due to dielectric absorption characteristics. Small size, medium stability, and long life expectancy under load.

Metalized polyester/polyester foil—
Values: .001 to 100 μF
Voltage rating: up to 1500 WVDC
Dissipation factor: 1% (at 25°C and 120 Hz)
Temperature range: −55 to +125°C (with 50% derating above 85°C)
Notes: See polycarbonate for typical applications. Moisture resistant and high insulation resistance. Small size, medium stability and very good load life. Capacitance will however vary widely with temperature. Foil units are generally lower cost than metalized types. Polyester film is commonly known as Mylar, which is a DuPont trademark.

Polystyrene foil—
Values: to 10 μF
Voltage rating: up to 1000 WVDC
Dissipation factor: .03% (at 25°C and 120 Hz)
Temperature range: −40 to +85°C without derating
Notes: Used in timing, integrating, and tuned circuits. High insulation resistance, and small capacitance change with temperature. Has excellent dielectric absorption characteristics. Large size with excellent stability and very good load life.

Paper/metalized paper/paper foil—
Values: to 100 μF
Voltage rating: to 5000 WVDC
Temperature range: −30°C to +100°C (derated by 30% over 75°C)
Temperature coefficient: greater than 4,500 PPM/°C
Notes: General purpose. Medium stability and very good load life. Large size; low cost. Metalized paper has paper coated with thin layer of zinc or aluminum and are smaller than metal foil units. They are, however, prone to dielectric breakdown of insulation resistance and have poor surge handling capability. Paper foil units used in high voltage/high current applications. Their dissipation factor varies with temperature. Maximum temperature is +125°C.

Polypropylene foil/metalized polypropylene—
Values: to 10 μF
Voltage rating: to 400 volts DC and 270 volts AC (foil units: 200 to 1600 volts DC and 300 to 440 volts AC)
Temperature range: −55°C to +105°C

Notes: Foil units are used in tuned circuits, integrating circuits, timing circuits, and CRT deflection circuits. Metalized units are used in DC blocking circuits. Good high frequency capability, high insulation resistance, close tolerance, high stability, and excellent dielectric absorption characteristics.

Less common types—
Polysulfone: Similar to polycarbonate and polyproplyene capacitors. Small size, high temperature range (to 150°C), suitable for high-frequency applications, and high insulation resistance. Excellent in high current and military applications. Not for sample/hold, fast settling amplifiers, or filters due to dielectric absoption characteristics. Poor history of availability.
Polyvinylidene fluoride: Considered experimental; Has high dielectric constant (about four to twelve times that of polyester devices), which results in a very small sized capacitor. Those units suffer from significant capacitance change with temperature, particulary at low temperatures.
Polyethylene terphthalate: For applications that require high reliability; high insulation resistance at high temperatures.
Metalized paper polyester/paper polyester foil: The foil unit has a slightly better dissipation factor than the metalized type. Operating temperature of −55°C to +125°C with voltage ratings of 240 to 600 (DC) available.
Paper polyproplyene: Available in voltage ratings of 400 to 800

(continued on page 87)

Capacitors

There are a lot of factors you should consider in selecting resistors for your projects and designs. As you might expect, the same holds true for capacitors. In capacitor selection, you should consider such things as operating temperature, humidity, AC ripple, and operating frequency. In addition, capacitance, as well as other capacitor specifications such as current rating, leakage current, voltage rating, and life expectancy, should be considered so that the device chosen will be appropriate for the application at hand.

Materials used in manufacturing a capacitor, as well as how those materials have been assembled, will effect capacitor specifications. As an example, capacitance is based upon electrode area and the type and thickness of the dielectric used. Varying any or all of those things will, of course, change the capacitance of the device. But that is not the only parameter that will change.

For instance, if the electrode surface area of an aluminum electrolyic capacitor is increased (to increase the unit's capacitance) through the use of finely etched electrode foils, the device will have a larger ESR (*E*quivalent *S*eries *R*esistance) than similar smooth-metal foil units. That is because the ESR depends upon the volume of the foil used.

You can also increase capacitance by using dielectrics with high dielectric (high-K) constants. But capacitors that use high-K dielectrics are not as stable (they are more sensitive to temperature and voltage variations) and generally have a higher dissipation factor than capacitors that use dielectrics with lower dielectric constants.

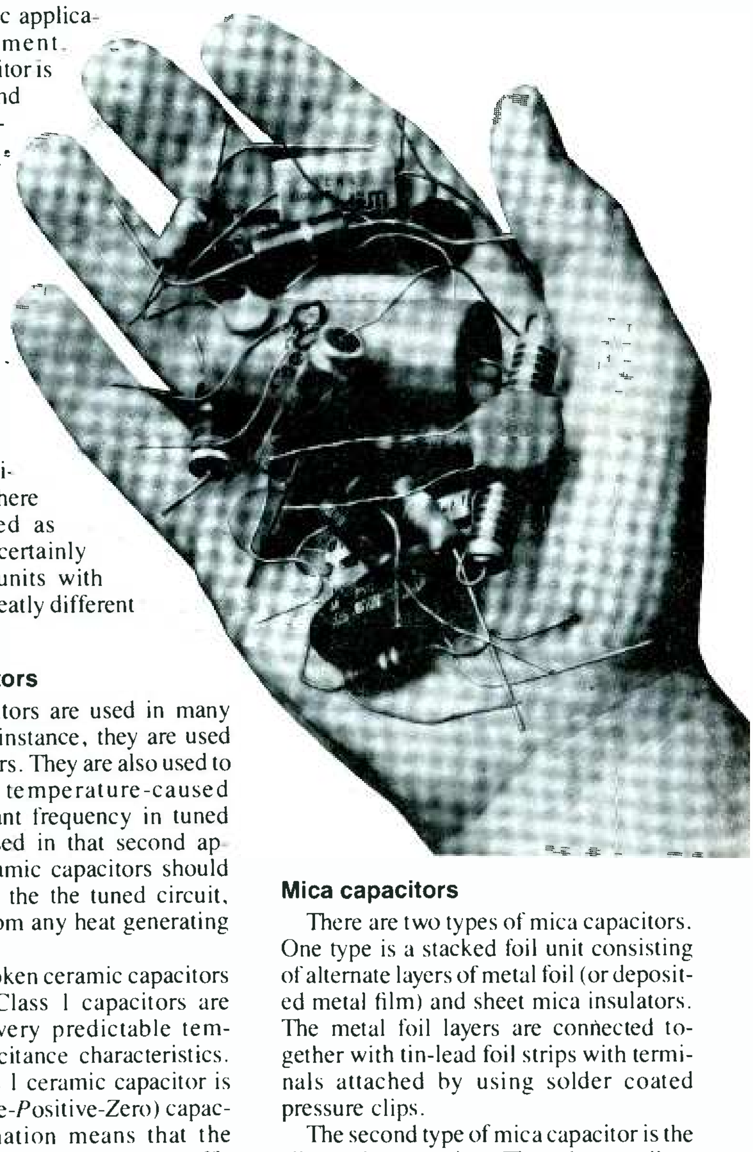
Capacitor package styles also should be considered. High lead inductances, common to tubular units, restrict high-frequency performance. Tubular ceramic capacitors however, are the most stable form of capacitor and, since there is no opposing electrode to provide stray capacitance pickup, almost the total capacitance is provided by the ceramic.

Dipped or molded radial-lead packages reduce interconnection impedances by allowing the capacitor to be mounted close to a PC board surface.

Chip capacitors have contacts, rather than leads, to even further reduce interconnection impedances. In addition, those devices are thin enough to mount beneath unsocketed IC's, thus reducing the length of a trace for a bypass capacitor. That is important in high-frequency circuitry since a printed-circuit board trace can have an inducance of 10 nanohenries/inch.

Capacitors come in a variety of styles including ceramic, mica, paper, plastic, aluminum, and tantalum types.

Each type was designed for best performance in a specific application or environment. Each type of capacitor is discussed below, and the important specifications and considerations that pertain to the type of capacitor are summarized in Table 2. Table 3 is a glossary of capacitor terms and specifications.



One note about Table 2—the specifications shown there are only provided as guidelines. It is certainly possible to find units with slightly, or even greatly different specifications.

Ceramic capacitors

Ceramic capacitors are used in many applications. For instance, they are used as bypass capacitors. They are also used to compensate for temperature-caused changes in resonant frequency in tuned circuits. When used in that second application, the ceramic capacitors should be mounted close the the tuned circuit, but be shielded from any heat generating components.

The EIA has broken ceramic capacitors into categories. Class 1 capacitors are those that have very predictable temperature vs. capacitance characteristics. One type of Class 1 ceramic capacitor is the NPO (*N*egative-*P*ositive-Zero) capacitor. That designation means that the negative and positive temperature coefficients of the device are zero and that they suffer almost (nothing is ever absolute) no change in capacitance vs. temperature. Other Class 1 capacitors have very predictable changes in capacitance with temperature.

For instance, a ceramic capacitor that is specified as N750 has a negative temperature coefficient of 750 parts-per-million, per-degree-centrigrade. That is, for each degree centigrade the temperature rises, the capacitance of the capacitor will drop 750 parts-per-million.

Class 2 capacitors are those that are non-linear. Their temperature coefficients are specified by a three letter code that specifies the low and high temperature ranges and the maximum change in capacitance from that at 25°C. Table 4 shows the EIA Class 2 code, and what the various designations mean. As an example, an X7R capacitor will vary in capacitance by no more than a factor of ±15% over the temperature range of −55°C to +125°C.

Mica capacitors

There are two types of mica capacitors. One type is a stacked foil unit consisting of alternate layers of metal foil (or deposited metal film) and sheet mica insulators. The metal foil layers are connected together with tin-lead foil strips with terminals attached by using solder coated pressure clips.

The second type of mica capacitor is the silver-mica capacitor. Those have a silver electrode material screened on the mica stampings, which are then assembled as described above. The silver-mica capacitors are very susceptible to silver-ion migration, which can occur within a few hours, when exposed to high DC-voltage stress, high humidity, and high temperature. The ion migration results in the capacitor short circuiting.

To keep internal inductance small for high-frequency use, button-style silver-mica capacitors have the anode connected through the center of the stack of mica sheets. The other terminal is formed by the case, which is connected to all points around the outer edge of the electrode. That design permits the current to fan out in a 360° pattern from the center terminal thus providing the shortest RF current path from the center terminal to the chassis.

One of the more common micas used for capacitors is Muscovite mica, which comes from India. That substance has a

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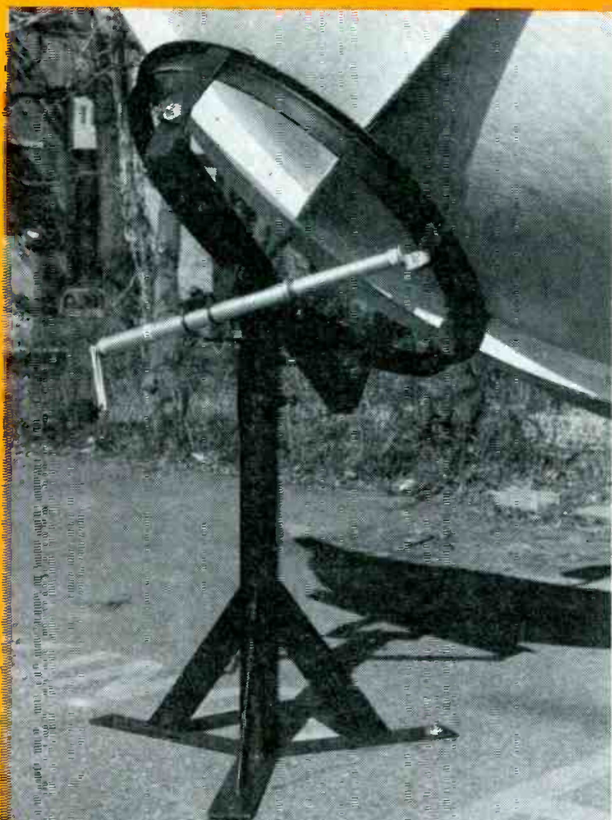
RECEIVING **Satellite** TELEVISION®



Know Before you Buy

Here are some things to think about before you buy that TVRO system.

BOB COOPER, JR.*
SATELLITE TV EDITOR

INSTALLING A HOME TVRO SYSTEM CAN BE A CONFUSING AND bewildering experience. That is especially true for a newcomer to the field of satellite TV. (Though such a newcomer brings with him none of the long held "old wives' tales" concerning the field; a person can know "too much" and consequently be leary of the often simplistic technical explanations and instructions that are so common in the TVRO field.)

Even so, installing the system is less of a challenge than the task of selecting the equipment. There is an entire family of "buzz words" in TVRO (even TVRO itself is something of a buzzword, standing for *Tele*Vision *R*eceive *O*nly), and they defy understanding to those who are "outside looking in." If you do not understand the buzz words, then the industry's literature is

*PUBLISHER, CSD MAGAZINE

virtually useless because most of it has been written with the belief that the reader is at least "versed" in the terminology. So where do you start? We hope here!

One or more?

We have developed a "chain of decisions" for you to follow in both understanding how a TVRO system works, and in formulating your own concept of how you might wish to select and perhaps install such a system for your home. We'll ask you some questions and from your answers we'll follow different routes to arrive at the equipment selection that most suits your needs. That will make it simpler for you to create your own system "on paper" since you will only concentrate on those system elements that pertain to the particular system design you have chosen.

Our first question is: Do you need to have control of your satellite program selection located at more than one spot in your home? That seems like an innocent enough question, but the answer has many ramifications, as we are about to learn.

The important thing to remember about program selection is that it can be done only at the satellite receiver. Satellite signals are in the microwave range, from 3700 to 4200 MHz. At those frequencies, cable losses are tremendous. To prevent that, the downconverter—essentially the first IF stage of a satellite receiver—is located outdoors at the dish. Since the IF is much lower than the frequency of the satellite signals, doing that allows ordinary coax to be used between the dish and the rest of the satellite receiver.

The drawback to that is that the selection of the frequency to be received is performed in that first IF, under control of the receiver. Therefore only a single frequency is carried over the coax line. That signal is fed to the receiver for further processing, and then fed to your TV, usually via either Channel 3 or 4. While it is possible (and economical) to share the satellite receiver output between two or more television sets located in the same home, it follows that the individual selecting the program from the TVRO receiver will in turn select the satellite-fed program for all the TV's fed from that receiver. A setup of that type is shown in Fig. 1-*a*. In that diagram, all satellite program selections are done at one site, called the master location; all other locations are called slave locations. It follows that having all the slave locations dependent upon the program selected at the master location may not be the most desirable system for your home, but how do we get around it? The answer is with *block downconversion*.

In block downconversion, the first IF stage passes the entire band of satellite signals. Selection of the satellite frequency you wish to view is done in a subsequent stage in the receiver itself. Since each receiver connected to the output of the first IF stage now has access to all of the satellite frequencies, each receiver can be used to independently select the signal that will be viewed.

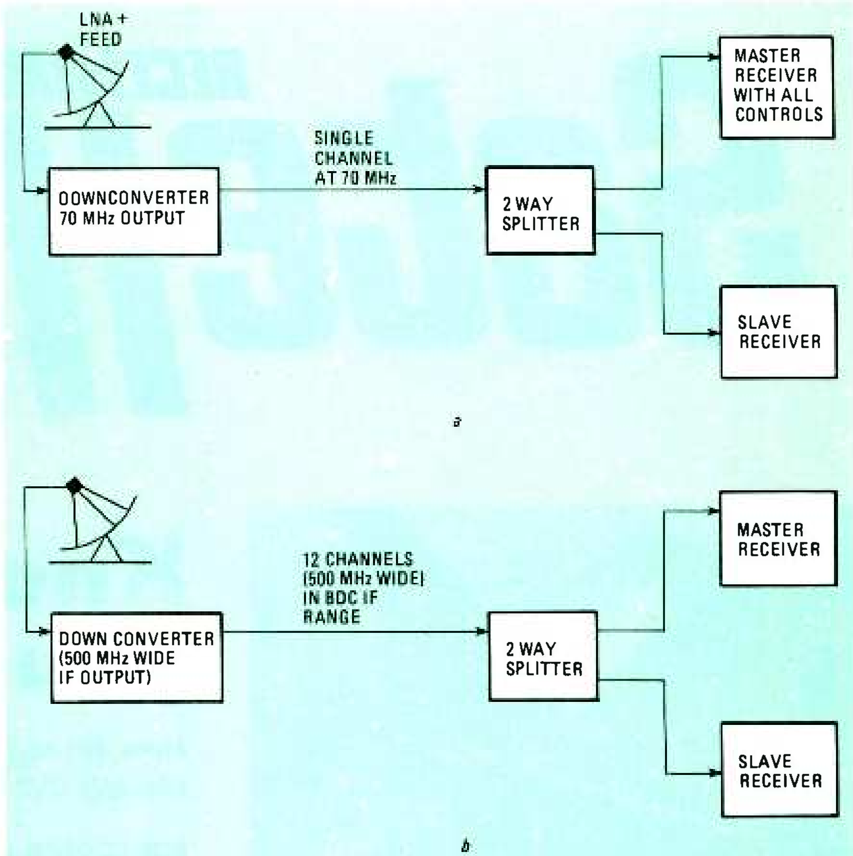


FIG.1—IN THE SYSTEM shown in *a*, only the transponder selected at the downconverter is passed to the receivers in the system; all receivers can be used only to view the same signal. In a block-downconversion system (shown in *b*), each receiver is free to select the channel that is to be viewed.

In a block downconversion system, we still have a master receiver and one or more slave receivers, although each receiver has the ability to independently tune in any transponder/channel they wish (see Fig. 1-*b*). We'll see why, shortly. For now, just remember that you do have a choice; the same program in all rooms on all TV sets as selected by the master, or individualized reception selected at any receiver location by either the master or attendant slave units.

Selecting the control location

Having selected a desirable approach to planning a home system, we now move into some of the subordinate questions you must face. For instance, let's consider dish control.

Whatever downconversion scheme you select, you must still decide how and from where you will move the dish. Here are some basic facts to consider:

- A modern satellite can carry as many as 24 separate TV channels or programs, simultaneously.
- There are more than a dozen satellites within view of a typical backyard dish located in most parts of North America. Virtually none of the programs or services repeat their transmissions on two different satellites, so you in effect have a potential of 24 × 12, on more than 280 TV channels in space right now. (As a practical matter, seldom do we find more than 90 of those potential video channels in use at any single moment.)
- To change channels, you first select the satellite you wish to view, and then select the channel you wish on that satellite. Changing channels is all electronic; changing satellites involves repointing the dish from one area of the sky to another.

Which brings us to the *dish positioner*, a device that uses either a motor-driven or manually operated mechanical arm to point the dish.

Moving the dish

It is now time to turn to our second question: Do you wish to be able to move your dish from one satellite to another by remote control?

That question presupposes that you will wish to move your dish somehow. If not by remote control, you can always trot out into the side or backyard and move it by hand when you wish to change satellites. Without a motorized dish, positioner system, your dish will most likely still have a mechanical arm that will allow you to do the same thing manually (overlooking the futility of trying to move the dish precisely, at 2 AM in the morning, during a thunderstorm or blinding snowstorm, dressed in your bathrobe!).

Turning to the motorized units, the basic dish positioner is a pretty simple device. It consists of a jackscrew connected to a motor with reversible windings, so the jackscrew can turn clockwise or counterclockwise upon command from a control unit located inside the house.

Perhaps we should note here that even if you've opted for a block-downconversion system, you will still be able to control the the dish positioner from only one location in the house. That's the reason one of the receivers in Fig. 1-*b* is still denoted as a master receiver. All other locations will still be able to select which transponder they wish to view, but not which satellite.

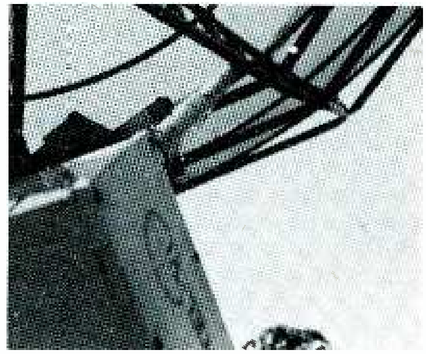
Getting back to the dish positioner, if the dish is properly installed, as the jackscrew rotates the dish will move in such a way as to track or follow something known as the Clarke Orbit belt. That's the arc in the sky, directly above the equator at a height of some 22,300 miles, where the geostationary satellites used for satellite TV are located.

The most basic dish positioners are much like the early home TV-antenna rotors that required that the user hold down on the button until the new TV station was peaked-in. They, too, require that the user hold down a button while the dish tracks across the sky.

But that task can get to be tedious. Consider, for instance, the following. Let's say you have been watching WTBS on transponder 18 on Galaxy 1 (G1). That's down low to the ground at the far western end of the satellite belt. It is a Thursday evening, and you decide you want to watch Boresight, a special program, intended for TVRO owners, that reports on new products and developments in the TVRO industry. That program is transmitted via transponder 20 on RCA F4, a satellite that is much higher in the belt. To repoint the dish from G1 to F4, requires that the dish track quite a distance through the arc, passing 8 to 10 other operating satellites along the way.

To repoint the dish, the first thing you do is set your receiver to receive transponder 20 (remember that transponder frequencies are the same on each satellite, making the job of tuning a lot easier). Then push, and hold down, the button that causes the dish to track to the east. Continue to hold down the button while the dish tracks across the sky. As you are tracking and passing satellites in the belt, the programming on transponder 20 on those satellites will appear on your TV. When you finally have the dish pointed at RCA F4, the Boresight program that you were looking for will appear. That tells you that the dish is correctly aimed and that you can release the button.

One problem with all of that is that the operation will typically take about 60 seconds. That's a long time to be standing there with your finger on a button.



A DISH POSITIONER is nothing more than a motorized jackscrew that extends and retracts upon command. Simplistic drive/controller packages provide east and west movement under pushbutton control, while more elaborate systems include location sensors and location memory.

THIS DISH CONTROLLER is just about the ultimate in luxury; its handheld infrared control can be extended to distant points in house for total control over the dish and system.

If holding a button down and waiting for the dish to move to the right satellite is not your idea of modern technology, prepare to spend extra money for extra convenience. For instance, dish positioners can be programmed, as we noted earlier, so that you simply push one (or two) buttons to tell the dish to move from wherever it is now to where (ie. which satellite) you want it to be.

A preprogrammed dish positioner naturally costs more than a non-programmed one, and one with a remote control costs even more. But a remote-controlled unit offers a significant advantage. With it, there are techniques available to allow you to extend the range of the remote control out of the room where the master receiver is located. And that is true whether your remote is of the infrared or RF variety. Let's take a look at an example.

In our example, the master unit is located in the family room where much of the TV viewing is done. But, there is also a slave unit in the bedroom. The question here is whether you should locate the master in the bedroom and the slave in the living room (weighing whether it is more inconvenient to get out of bed to change satellites than it is to get out of a chair.)

Remote control to the rescue.

The range of infrared remote-control units can be extended with remote pickups all over the house; anyplace you can run a wire back to the master receiver can be a secondary pickup point for an infrared unit. And, if your remote is of the RF variety, its signals will not be impeded by such things as walls and floors, so you can simply wander with the remote and change both channels and satellites from anyplace in the house.

Picture quality

Our next question is: "What level of picture quality is acceptable?" Before you answer that, however, perhaps we should rephrase that to read: "What level of picture quality are you willing to pay for?" The following may help make that decision a little easier.

You have doubtless heard that having a satellite system in your home is the next best thing to being inside a network control room. And it in fact can be. But it can also be a test of your eyesight since there are many low-cost, marginally performing, home systems. Perhaps a good analogy would be to compare those low-cost systems to a shirt pocket AM radio, that for $3.95 does indeed "receive" AM signals. But, as you might imagine, how well it receives them for that price is an entirely different matter.

You will have to decide what level of picture quality you want for your system and, as you might suspect, the better the quality, the higher the cost. According to recently conducted national surveys, the average home TVRO system, installed by a dealer (often referred to as a turnkey system), costs just under $3000 ($2993, if you like exact figures). Yet you have most likely seen advertisements for complete systems that you can install yourself for under $500. On the other hand, there are systems on the market that even today can run $8000. Logic should suggest that the $8000 system must do something the $500 system does not do, or the guy selling the $8000 systems would shortly be in another line of work.

What are those differences? There's convenience, for instance. You will certainly not find such things as motorized dish positioners or remote control on a $500 system you install yourself; those are items found only on upper-price bracket systems. But what about reception quality?

There are three factors that directly effect the quality of the reception you can expect. We'll try to deal with each in such a way that you will understand the trade-offs involved.

One of those factors is dish size. With present technology, it is not yet possible to produce as clear pictures from as many channels with a 6-foot dish as it is with a 12-foot dish. Dish size relates directly to dish gain, or the sensitivity of the system.

It would be nice to be able to tell you

that with a 6-foot dish you will receive 47 channels, with an 8-foot dish 52 channels, with a 10-foot dish 68 channels and with a 12-foot dish 92 channels. Unfortunately, we cannot do that because how many channels you can receive, and at what quality level, also depends on where you install the dish.

Between the Hughes (Galaxy), RCA (Satcom), Western Union (Westar), AT&T (Comstar and Telstar), Canadian (Anik) and other satellite families now littering the Clarke Orbit belt, we have many different philosophies of how a satellite should beam its signal toward earth. RCA, for example, believes that all satellites should favor the mid-western part of the U.S. with gradually weaker signals in all directions (towards both coasts). Hughes believes that all satellites should cover significant parts of a hemisphere (which is substantially larger than the U.S. alone). AT&T sees no reason to cover anything but the 48 continental states.

That means that the signal strength received on the ground (the pattern of signal strength is often referred to as the satellite's footprint) varies from location to location, and from satellite to satellite. A 6-foot dish in Florida works poorly on Satcom, but better on Galaxy. A 10-foot dish produces perfect AT&T (CBS and ABC) network signals in Kansas, but produces virtually no pictures at all in the Bahamas. We could fill pages with that kind of information, but all it would do is confuse you. Instead, we offer the following:

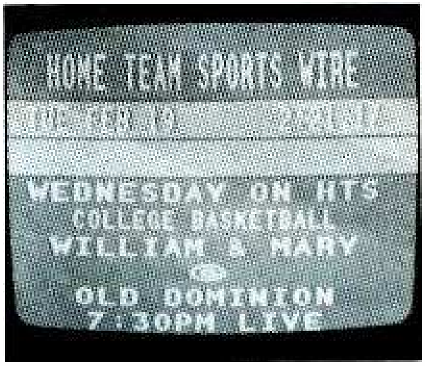
- People who live in the central part of the U.S. (such as Kansas and the surrounding states) are best off because most satellites at least maintain maximized signal strengths into the center of the U.S.
- People who live in New England and Florida are worst off with the exception of those who live in Hawaii, because both of these portions of the continental land mass are least favored by most of the satellites that carry video programming. (Hawaii, because of its distance from the continental U.S., is covered only by low-power spot beams. Only about 50% of the available channels are carried by those beams, and because of their low power, dishes less than 12-feet in diameter are generally not useable.)

Which brings us to a completely unreliable rule of thumb: Use bigger antennas around the edges of the 48 continental states and use smaller antennas as you get closer to the central states.

Now, here's why that rule of thumb is completely unreliable. A 6-foot dish in New Jersey will work quite well; but only on certain of the Galaxy and Satcom transponders. If a person will be happy (as in satisfied) with say 15–18 clean channels and a multitude of others that are not clean (as in snow and interference), he's a candidate for a small dish at a cheap price, even in New Jersey, Connecticut, or Florida. If he took the same small dish to Kansas, Oklahoma, etc., he'd find 50 or 60 clean channels to watch.

Now, how do you find out what kind of dish you are going to need or want to be satisfied? Check around your own area. Inspect dishes that have been installed and see what the reception looks like.

- Ask to see transponders 2, 4, 10, 14, and 22 on RCA Satcom F3R. Those are universally weak. If they look clean, you are probably watching a good performing system for its size, in the 48 states.



INCREASING THE DISH SIZE to 12-feet provides a rock-steady, noise-free signal.

- If you are west of the Rockies, ask to see transponder 21 on F3R (The Weather Channel). If it is not perfect, the dish is probably not large enough.
- If you are along the east coast, ask to see transponder 8 on F3R (CBN) and transponder 5 on Galaxy 1 (Showtime). Again, they are weaker than the others and as such will help you judge a system's performance.
- If you are outside the U.S., in the Caribbean, ask to see all of the above plus Telstar 301 (96 degrees west), transponders 2 and 10 for the CBS and ABC network feeds respectively.

Another factor influencing the quality of the reception is the sensitivity of the *L*ow-*N*oise *A*mplifier, or LNA. This is the signal booster/amplifier that is installed at the dish proper. They are rated in two-ways: by something called noise temperature, and by their gain.

Noise temperature is a measurement performed on LNA's to determine how much noise they add to the satellite signals while they amplify them. Noise is bad, clean signal is good, therefore an LNA that adds less noise is better than one that adds more noise.

Noise shows up on the screen as snow (called sparklies in the TVRO trade). Noise degrades the picture and sound. LNA noise temperatures fall between 55 degrees and 120 degrees Kelvin at the present time. A 55-degree unit is more expensive than a 120-degree unit. Most systems sold today routinely use 85- or 100-degree units because they are cost effective. There is not a great deal of price difference between an 85-degree unit and a 120-degree unit anymore (not at the dealer level, anyhow). But the 55-degree units can still cost from two to four times as much as a 100-degree unit.

Gain is important too, but here you almost have to take the word of somebody who has selected the component units for you. Some receivers work no better with a 50-dB gain LNA than they do with a 40-dB gain LNA. In some systems, the trend is to take some of the gain away from the LNA (such as dropping it from 50 dB to 40 dB) and then to make up for it by adding additional gain stages in the receiver proper.

Then again, some receivers don't use LNA's; they use LNB's or LNC's. An LNA is a stand-alone amplifier that does nothing but amplify. It is followed by a stand-alone downconverter that does nothing but convert frequencies. An LNB is a *L*ow-*N*oise *B*lock downconverter, which means that the amplifier and a block downconverter are packaged in a single housing or container. The LNB now has a noise temperature rating but it will no longer have a gain rating since the gain is part of the converter package and the meaning of that rating is lost in the marriage of the two units.

An LNC, or a *L*ow-*N*oise *C*onverter, is the combination of the LNA and a standard-type downconverter. Again, they are rated with a noise temperature but not a gain specification.

Which is best is not an easy question to answer since no *one* is really best. That's because those units are part of a system and are worthless unless connected to a receiver. A really great LNB, for example, will not produce good quality reception when connected to a system with a not-so-good receiver.

Fortunately, most of the people who make receivers also make or offer an LNB, LNC, or stand-alone downconverter to which the installer adds an LNA as part of a complete receiver package. So you are not likely to run into the option of selecting which amplifier will go with which receiver.

Some people—including many satellite-TV dealers—believe that you can trade off low noise temperatures for smaller dish size. For example, you may be told that you have the choice between an 8-foot dish with a 75-degree LNA or a 10-foot dish with a 100-degree LNA. They may even tell you that the performance will be the same with either choice.

That's simply not true. A lower noise LNA can help make up for the shortcomings of a smaller dish, but you can't entirely get back the gain lost by cutting back the dish's diameter two feet by using a better LNA. In other words, you can't recover a signal that you never had in the first place.

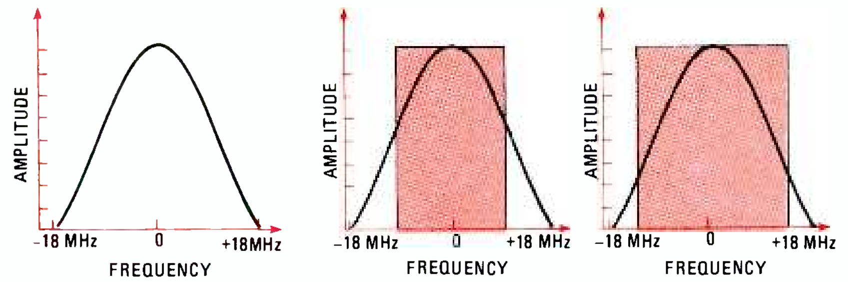


FIG. 2—WIDE VERSUS NARROW BANDWIDTH. While most video information is concentrated in the center portion of the signal (see *a*), luminance and color detail information is found at the signal edges, as is the majority of the noise. Using a narrow bandwidth IF (see *b*) allows most of that noise to be cut-off, but at the expense of the color detail and luminance. Using a wide bandwidth IF (see *c*) allows all of the picture information to be processed, but will also provide a noisier picture.

IF bandwidth

Finally, the third factor is receiver IF bandwidth, a parameter that has a direct bearing on the quality of the pictures you receive. Take a look at Fig. 2-*a*. It shows how the energy of a typical satellite TV signal is concentrated. Note that the majority (about 90%) of the energy is concentrated in the center portion of the signal. As a result, the signal strength in that region is high enough to override the natural noise level. (Noise is caused by a variety of sources including atmospheric conditions, local and space interference, sunspots, etc. As a result, for a signal to be useable, it must override that noise "level.") But at the outer edges of the signal, the concentration of energy is much lower and the noise is no longer completely overridden. Because of that, about 90% of the noise in a signal is found at the edges of that signal.

It is of course possible to design a receiver with either a narrow or a wide IF bandwidth. With a narrow bandwidth, as shown in Fig. 2-*b*, the band edges are cutoff, allowing only the stronger central portion of the signal to pass. With a wide bandwidth, as shown in Fig. 2-*c*, all of the signal, as well as all of the noise pass.

Now, with 90% of the picture information contained in the central portion of the signal, it would seem logical to go the narrow bandwidth route to obtain as noise-free a signal as possible. There is one major flaw to that, however.

That flaw is that two important parts of the picture information are contained in that ten percent of the signal that is thrown away. Those are the depth-of-field of the color and the high resolution detail in the black and white. To retain all of the color depth and all of the luminance (black and white) detail, you need a to go the wide bandwidth route.

If the satellite signal is good and strong, you can afford to select a wider bandwidth since the sheer strength of the signal will allow the receiver to display a high quality, noise-free picture even with that wider bandwidth. On the other hand, if the signal is weak (because of your having chosen a smaller-than-recommended dish, because of your location, or both), you may need to sacrifice color and detail to get a useable picture.

Receiver data sheets specify IF bandwidth. Some go for the narrow end, a few go for the wide end. Most hang out in the middle, with bandwidths between 24 and 26 MHz.

One last point before we move on. If your installation includes a projection TV, you may not have a real choice as far as bandwidth is concerned. That's because those sets "blow up" the image significantly. What was a small blemish on a 12-inch screen (and perhaps not visible to the naked eye) becomes a glitch or glob on a four- or six-foot screen. Worse than that, when you take a picture designed to be viewed on a 19-inch tube and blow it up to projection-TV size, the scanning lines themselves become visible. And when your satellite receiver has lost the depth-of-color and the luminance detail because of a narrow receiver bandwidth, the picture becomes fuzzy and indistinct; it simply loses its ability to be a pleasing, well defined video image.

So when the installation includes such a set, the best advice is to stick with a dish that's large enough to allow you to use a receiver with a wide bandwidth.

Audio considerations

Satellite television "broadcasting" is not broadcasting at all. It was never intended to be a system to transmit individual programs to individual homes; it sort of wound up that way because people got together and starting building equipment that would receive the satellite signals.

Satellite television is simply a relay system, using a single repeater station in-the-sky to relay uplinked microwave signals to stations around the country. Consequently, unlike regular TV, AM, or FM broadcasting, no regulatory agency has ever prescribed technical standards to which every satellite program relayer must adhere (aside from rules governing interference to other users).

As you might expect in such an environment, there are a number of different audio formats currently in use (currently 16, though it is expected to grow to as many as 26 within a year). And the audio that is relayed is not limited to just the video signal's audio channel (or channels in the case of stereo). Each transponder has numerous audio subcarriers that carry a wealth of subsidiary services.

Which leads us to our next question: Are you interested in the program audio for television only, or do you also want the non-television audio services?

Program audio (the audio that accompanies the video signal) is normally transmitted on a specific subcarrier frequency between 5 and 8 MHz; for example, 6.8 MHz. A TVRO receiver has a tuning knob that allows continuous tuning of the subcarrier frequencies. As a point of information, around 80% of the program audio subcarriers are on 6.8 MHz, another 10% are on 6.2 MHz and the balance are scattered between 5 and 8 MHz.

You might expect that the program audio on the various satellites and transponders would follow a more-or-less uniform format. Unfortunately, that is not the case. For instance, consider audio bandwidth. Because there are no FCC or even industry standards to follow, the programmers have been free to choose almost any bandwidth that suits their needs.

That has put the satellite receiver designer in a bind. That's because while most program audio is transmitted with an FM (deviation) bandwidth of around 250 kHz, some are far greater. The Nashville Network and The Disney Channel, for example, have bandwidths that are closer to 500 kHz. To get around that, most receivers give you two selectable audio bandwidths, labeled narrow and wide.

If the receiver you use does not have an appropriate bandwidth for the audio signal you wish to receive, it is obvious that the reception will not be satisfactory. When you tune in an audio subcarrier that is wider than the receiver's bandwidth, the audio sounds muddy and indistinct. When you tune in subcarrier that is narrower, on the other hand, the audio sounds scratchy or noisy. Therefore, you want to select a receiver that has an appropriate range of bandwidths for the services that you are interested in receiving. We'll return to some tests you can conduct to determine that shortly.

So far we have been concerned with program audio. It is possible for a transponder to transmit not only its own program audio, but also a considerable number of non-TV-program related audio (see Fig. 3-*a*). The WGN transponder (F3R, TR3), for example, has more than a dozen subcarriers that carry material that has nothing to do with the television. Some of those are data signals, while others are music broadcast services intended for use by AM and FM radio stations.

Satellite Music Network, as an exam-

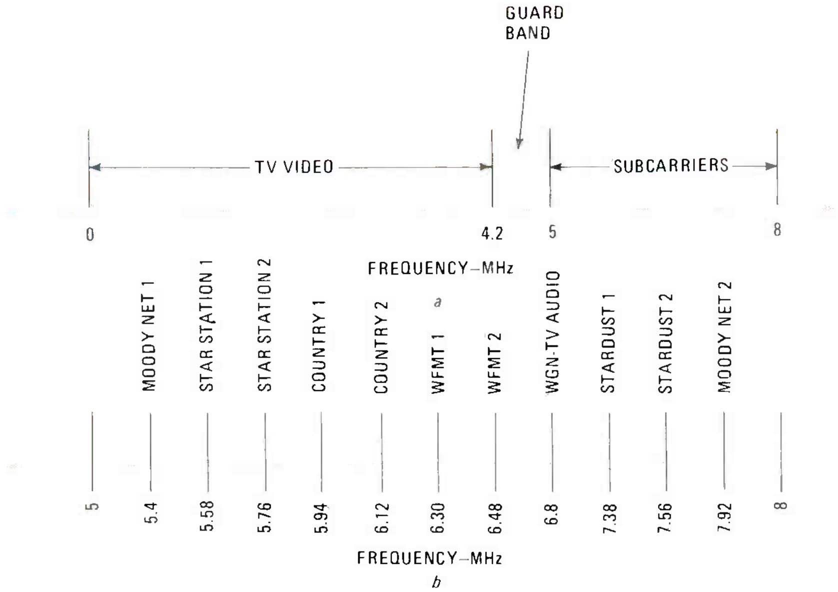


FIG. 3—A TYPICAL TRANSPONDER SIGNAL consists of the video signal, a guard band, and a number of audio subcarriers (see *a*). The audio subcarriers for F3R, transponder 3 (WGN) is shown in *b*.

ple, uses several subcarriers on the WGN transponder to carry an adult contemporary music service, a country and western music service, and an MOR (*Middle Of* the *Road*) music service. Each of those is transmitted in stereo (see Fig. 3-*b*).

And stereo brings in a some further complications.

We've already mentioned that there are many different systems used to transmit monoaural audio. There are, as you might by now have guessed, also different techniques used to transmit stereo sound.

When the left audio is transmitted on one channel and the right audio is transmitted on another channel, we have what we call discrete stereo. To receive discrete stereo, the receiver designer has to build into the TVRO system two separate audio subcarrier tuners; one of which the user tunes to a designated subcarrier frequency (such as 5.58 MHz) and the other of which is tuned to another separate subcarrier frequency (such as 5.76 MHz.). One audio channel is found on one of the subcarriers, the other channel is found on the second subcarrier. The system connects to the in-home stereo system simply by connecting the right output of the TVRO receiver audio to the right input on the stereo, and so on.

Not all stereo is transmitted in that format. Some are transmitted in a matrix format. There are still two separate signals, but each involves mixing the left and right channels in a L + R, L − R format. It still requires a pair of subcarriers. One might be on 5.80 MHz and the other on 6.80 MHz, for example. With that system, the user tunes one of his subcarrier tuners to 5.80 MHz, and the other to 6.80 MHz, and inside the TVRO receiver, matrix decoder circuits separate the right and left signals so they can once again be fed to a home stereo system.

Now some buying tips.

Your first concern is that the receiver that interests you will be compatible with the level of audio services you desire. Regardless of whether you want stereo or not, you do want clean program audio. It may be difficult to ascertain what is clean and crisp if you are trying to listen to a two-inch speaker crammed into the side of a TV set. So ask to have the audio fed through a good sound system.

Now, how good is the audio system? Here are some benchmarks.

- Tune in transponder 6 on F3R (SPN/Satellite Program Network). Place the receiver in the narrow position and look for the next-to-highest subcarrier (7.695 MHz); it will be a "comedy channel" (famous comedians doing comedy routines). See if the audio is noisy. That service uses a very narrow bandwidth, and if the narrow position provides clean, crisp sound here, then the receiver should do a good job with all narrow-bandwidth signals.
- Tune in transponder 4 or 24 on Galaxy I (The Disney Channel). If the receiver is stereo capable, set it for mono, and select a wide bandwidth. Now tune in the audio at 6.8 MHz. Check to see if the audio is "muddy" sounding. That audio channel uses a very wide bandwidth and if the audio is crisp and not muted, that receiver should have no problem with most wide bandwidth audio signals.

Perhaps more so than the video sections, the audio sections vary widely in performance between different receiver models and brands. There is a possible alternate solution if you fall in love with a receiver that has great video but not all of the audio features you would like (not all receiver designers have hopped on the "tune-every-audio service" bandwagon yet).

Stand-alone audio subcarrier tuners are available from a number of sources. Those allow you to treat the audio independent of the video. Again they, like the TVRO receivers with built-in audio tuning controls, should be compared as we previously suggested, since the mere fact that it is a stand-alone audio subcarrier tuner is no guarantee that the designer has allowed for the proper blend of audio bandwidths in use.

Avoiding hype

When home TVRO systems first came into the marketplace, all dishes were large, all dishes moved by hand (if at all), and everything cost a great deal of money. Today, fully 70% of the LNA's, 60% of the receiver's, 20% of the motor drives, and 10% of the dishes are created outside of North America. And the percentage of products being manufactured off shore has been getting larger by the month.

Panasonic and Uniden have been recent non-U.S. entrants into the marketplace. Numerous U.S. firms, although still branding their products as "U.S.-made, now are having assembly done in Korea, Taiwan, Hong Kong, or even Mexico. Even Europe is in the North American TVRO act (Luxor from Sweden). With nearly 500,000 home systems sold during 1984 and up to 750,000 home systems forecast for 1985, the market has become large enough to attract many of the better known volume producers.

It is, however, a marketplace that exists almost exclusively within North America and the surrounding areas (where US and Canadian satellites can be received). That is not likely to change in the foreseeable future since North America utilizes certain satellite frequencies and those satellites provide certain services that exist no place else in the world in the same format.

If you are reading this overseas, the first bit of hype to avoid is that you can buy a satellite dish and watch HBO in Ghana, Singapore, etc. The world of international satellite reception is an entirely different subject from that addressed here, and the $500 to $8000 systems we have discussed won't even dent the requirements you will face outside of North America or the Caribean.

The next bit of hype to avoid deals with signal scrambling. The present industry exists to some extent because with a home

STAND ALONE audio subcarrier tuners allow you to treat the audio separately from the video.

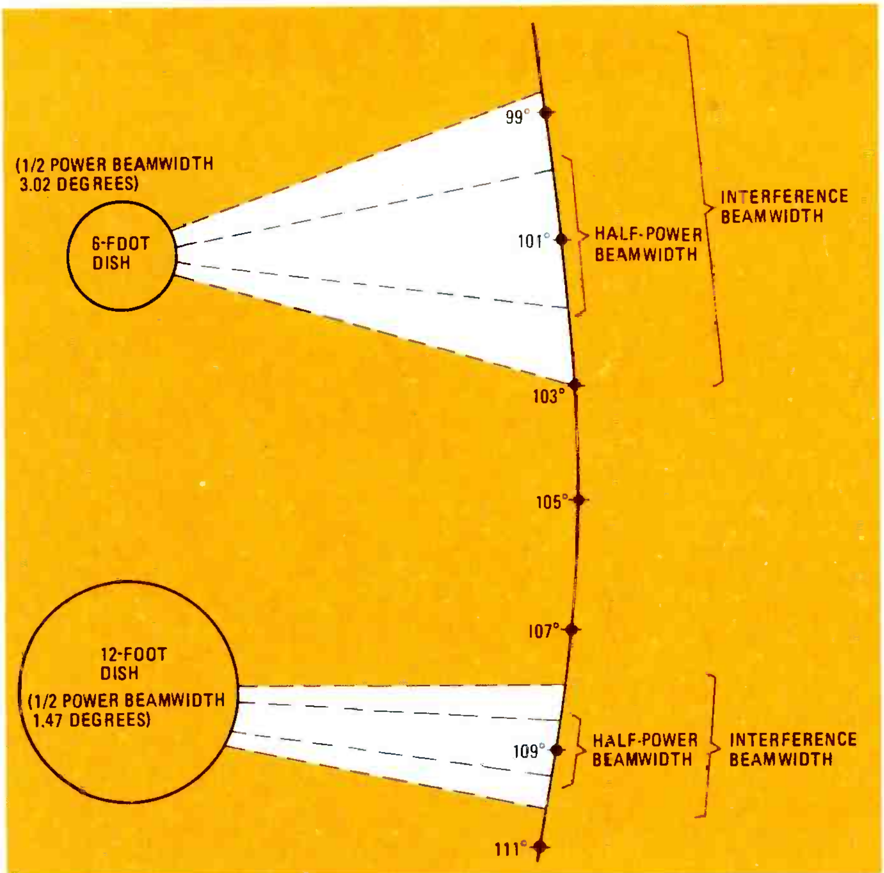


FIG. 4—THE DISH'S SIZE directly affects it beamwidth. As is shown here, the smaller diameter the dish, the larger the beamwidth. That can prove to be a problem for small diameter dishes if two-degree spacing is used. In that case, signals from adjacent satellites can be a source of interference.

TVRO you can tune in satellite program feeds from services such as HBO and Showtime. For many years those services have been open, or available to anyone with a TVRO. And for many years, there have been rumors and there has been speculation that some (or all) of those services will scramble.

Naturally if a substantial quantity of those 90 or so real TV channels did scramble, the desirability of owning a TVRO might change.

As you read this, at least HBO and Cinemax are virtually ready to turn on scrambling equipment. Showtime and The Movie Channel have announced they will also scramble. So, does that spell the end of TVRO?

Not at all. The programmers, if and when they scramble, are doing so because the home TVRO market is now reaching a point where the programmers can anticipate some new, additional revenues from TVRO's. They want to do business with TVRO system owners and after they scramble, there is every reason to expect that they will make their services available to you for a reasonable monthly fee; not unlike cable TV charges for the same services. So the hype that all signals will scramble (four out of 90 is hardly all) and TVRO's will be useless is just propaganda from ill-informed reporters.

The final bit of hype to avoid deals with super-small systems using dishes in the four foot to less-than-seven foot category. We already know that small dishes have less gain, and even in Kansas (where signals are generally strongest) people still prefer 10-foot dishes. They also will have problems dealing with two-degree spacing. Let's see more about that.

Satellites, as we have seen, stretch across the sky in a belt over the equator. Each satellite is assigned an orbital slot by some agency (such as the FCC in the U.S.). The satellite stays within 35 miles of that slot at all times; if it wanders, its orbit is corrected via telemetry. That is important because if a satellite were to wander considerably, it would be difficult to track with a satellite dish, and its signals could interfere with those from an adjacent satellite.

In fact, it is because they are sufficiently apart in the sky that the whole system works at all, since they do use the same channels and we depend upon the directivity of our dish to look only at a single satellite at a time. That directivity is called the dish's beamwidth, and that beamwidth depends greatly on the diameter of the dish—the larger the dish's physical size, the narrower or smaller that beamwidth (see Fig. 4). So, small dishes have broad beamwidths and big dishes have narrow beamwidths.

Now to our problem. The FCC wants to cram as many satellites into that portion of the sky set aside (by international agreement) for U.S. (and Canada/Mexico) use as possible. They want to move the satellites closer together, without causing interference between satellites to the users on the ground. At the present time, U.S. satellites are spaced 2.5 to 4 degrees apart in the Clark Orbit belt. The majority of the present satellites are at least 3 degrees from their neighbors, but the FCC warns us that within the next five years or so, they want to make all satellites uniformly 2 degrees apart.

The catch for small dish owners is that those dishes under 8 to 10 feet in diameter have no proven ability to still function properly when satellites get down to 2 degree spacing. And smaller dishes, 6 feet in size and down, will almost surely have very real problems. With those dishes, when you are pointed at the desired satellite, signals from other satellites on both sides, two degrees away, will certainly cause some amount of interference. Your satellite receiver, seeing both the desired signal and the non-desired signals will simply treat the non-desired signals as interference or noise. The bottom line will be less-than-perfect reception.

To be sure that your dish will still be useable when 2-degree spacing becomes the norm, our advice is to get a guarantee. Most responsible dish manufacturers will certify to you, in writing through the dealer, that their dish will function with two-degree satellite spacing.

Warranties and guarantees

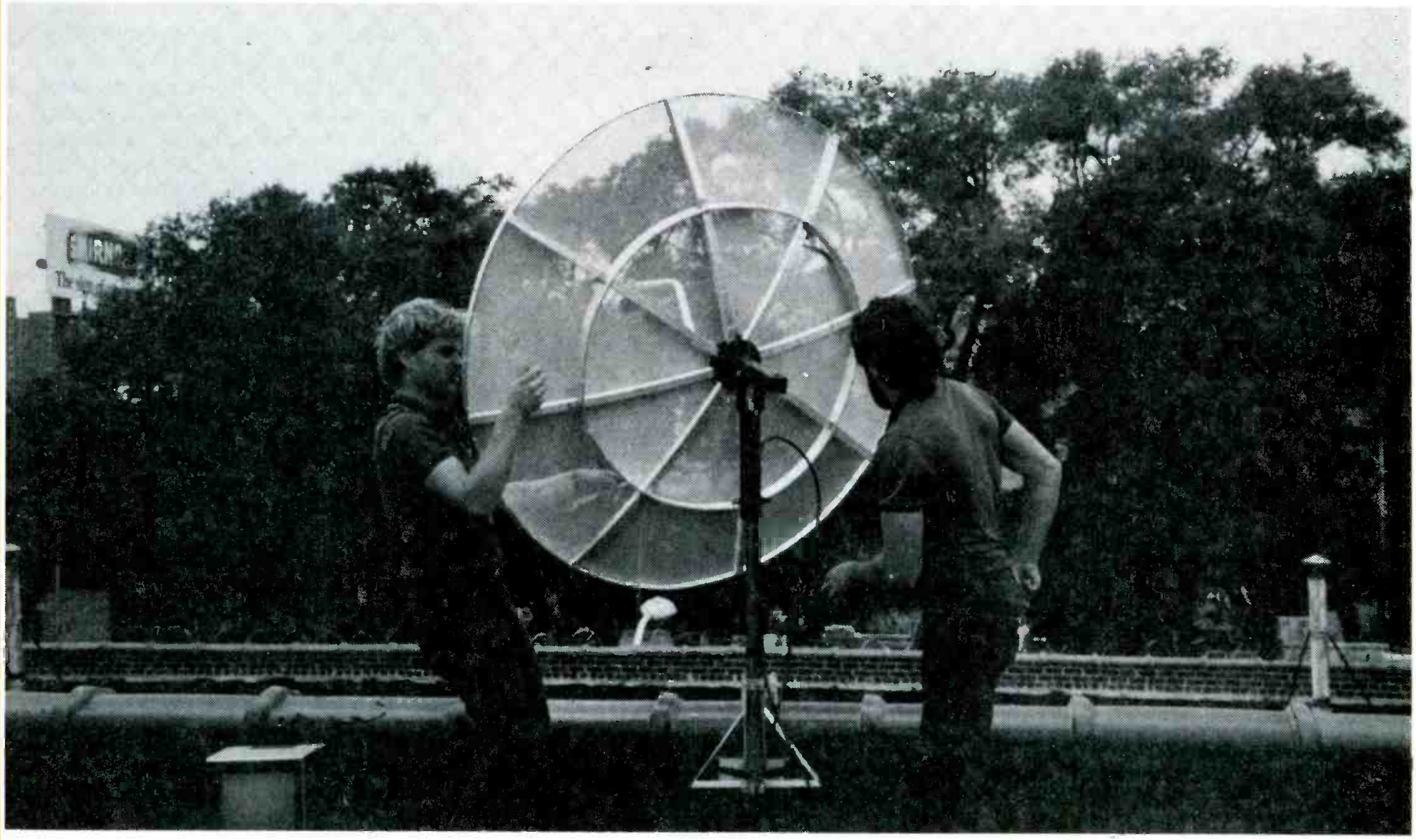
Finally, we leave you with this observation. Early TVRO products were only as good as the local dealer's ability to cope with failures and to respond to the customer/user's plea for assistance. But, times are changing.

Well over 50% of all electronic units and perhaps an even greater percentage of dishes now carry manufacturer warranties. A 12-month original equipment manufacturer promise of performance or replacement statement is pretty standard these days, and some extend to two years and more.

Your bill of sale should make direct reference to the warranty/guarantee coverage and if the original equipment manufacturer provides his own printed statement, that document should become a part of your records—just in case.

The TVRO product area has become far more sophisticated, in both technology and business experience at the dealer level, in just the last 12 months. The industry is a rising star that many expect to continue to grow rapidly for the next five years or more. These may no longer be the pioneering days of yesteryear, but there is still plenty of excitement and challenge in finding the right equipment package for your own home. **R-E**

Installing your TVRO



BOB COOPER, JR.* SATELLITE TV EDITOR

Take the guesswork out of TVRO installation with this step-by-step guide.

THE FIRST STEP IN SETTING UP A HOME TVRO system, before spending even one dollar on equipment, is to sit down and do some thinking. For instance, have you given any thought to where the dish is going to be located? Unfortunately, for reasons we will get into in a moment, not every yard can accommodate a dish. If yours turns out to be one of those, you could try to place the dish on your roof; but that requires some special mounting considerations, as a dish elevated in that manner is subjected to quite a bit of wind and ice loading. An improper installation can lead to a damaged dish, or worse, a damaged house.

When you are planning out where you are going to locate your dish, there are certain rules that should be observed:

- The satellites are located in a belt over the equator, at a height of 22,300 miles (see Fig. 1). If you are in North America, that generally means that the satellites will be south to southwest of you.
- The majority of satellites transmit back to earth using frequencies in the 4-GHz band (also called the C-band). That is a microwave-frequency band and like all other microwave signals, there can be no physical obstructions between the signal source (the satellite) and the dish. Thus your dish should be located so that no buildings, trees, hills, or other "obstructions" block its view to the south or southwest.
- The satellites that are located due south of your location will be the ones that are the highest in the sky. Those located to the southeast or southwest of your location will be located close to the horizon (i.e. close to the ground). We specify a satellite's position in the sky, from your location, using something called look angles. There are two look angles that count: how far up or above your horizon the satellite is located, and the angular bearing from your location to the satellite's location.

The "up" direction or angle is called the elevation. It is the angle formed by a line drawn from your dish to the horizon and a line drawn from your dish to the satellite of interest. The angular bearing is called azimuth and it is referenced to true north (with true north being 0 degrees). Thus, a satellite due south of you would have an azimuth of 180 degrees, while due southwest would have an azimuth of 270 degrees.

Note that our reference point is true north. Because the north pole and the magnetic pole are not in the same location, the compass that points north may actually be pointing ten degrees or more away from true north. When we lay out or plan a system, and we try to determine if we have any blockage from our intended dish location toward the satellite, it is important that we correct our magnetic north to true north if there appear to be any close blockages in the area.

The local airport control tower, the local survey office, a stationary or engineering supply store that sells USGS Geodetic Survey Maps will have available to you the proper magnetic correction to be applied to a compass reading for your locale. If your location is Colorado, for example, the compass will point 14 degrees west of true north. Once you have the proper correction factor, it is a simple matter to de-

*PUBLISHER, CSD MAGAZINE

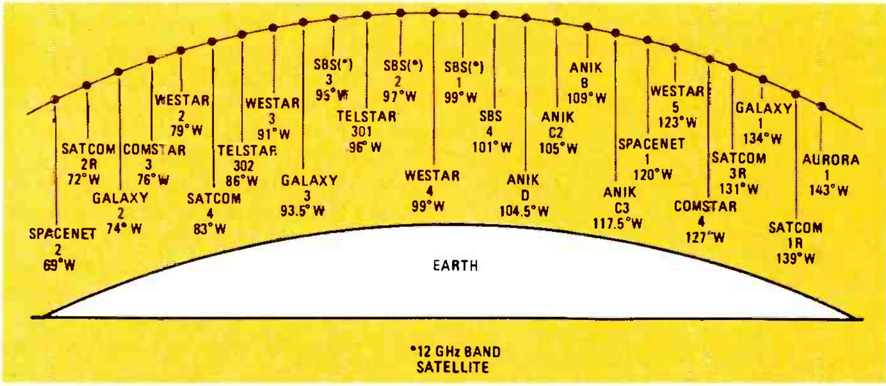


FIG. 1—CHARTING THE SATELLITES. The positions of all North American satellites in the Clarke Belt are shown here.

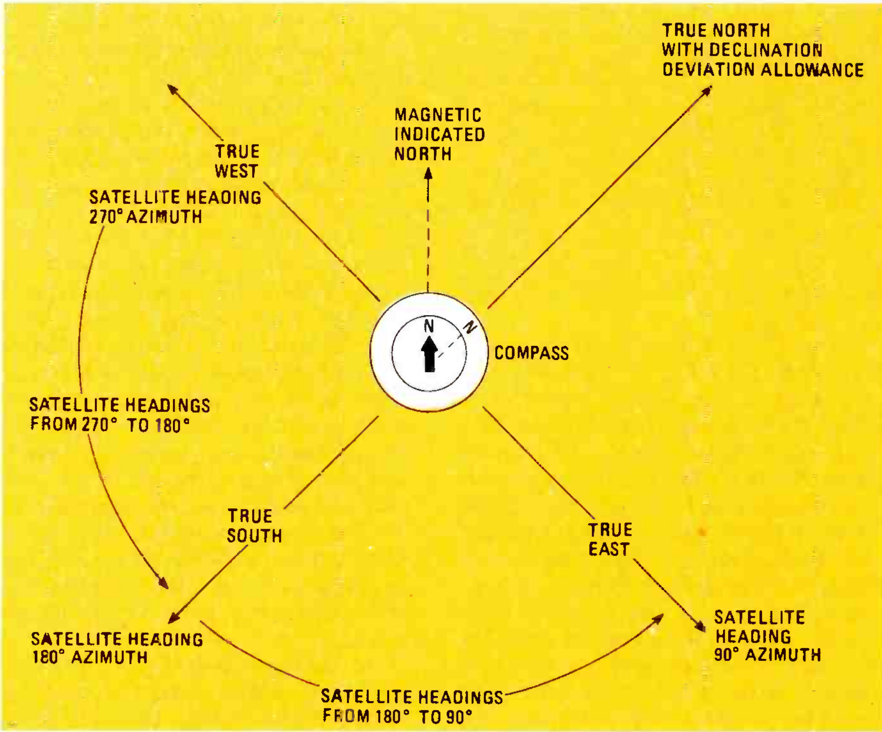


FIG. 2—WHEN DETERMINING WHERE a satellite is, relative to your location, be sure to allow for the difference between magnetic north and true north.

termine the direction of true north and to use that information to locate the azimuth headings of the various satellites (see Fig. 2).

We now know that the satellites are located more or less to our south, and at some elevation above the horizon. But we still don't know exactly where they are. Unfortunately, we can't provide a simple answer to that, as the answer varies from location to location.

So it is still somewhat difficult to calculate which location on our property might have a clear access or view to the satellite belt. To do that properly we need a reference source, some type of "pointing guide" that will allow us to take our own location (by geographic latitude and longitude coordinates) and then determine that our view of the desired satellites is clear. A full description of that subject is beyond the scope of this article so we will give you some other choices:

- Find somebody locally who already has that information for your area (as we said, the settings do change with each locale or region, since your latitude and longitude to the nearest degree determines how you need to point your dish).
- Invest $15.00 or so in a satellite aiming guide. For instance, *World Satellite Aiming Guide* (PO Box 2347, Shelby, NC 28150) provides an aiming guide for $15 that allows the user to find the elevation and azimuth settings for virtually any satellite from any location. It can be a bit difficult to use, but it does get the job done.

AN "INCLINOMETER" is a valuable tool in TVRO installation. Here we see how one commonly available unit is used.

If someone in your area already has a TVRO, you could also use a compass and an "inclinometer" (a device used to measure elevation angles) to measure the various look angles. (One commonly used inclinometer is the Craftsman *Universal Protractor, Plumb & Level*, available from your local Sears.) To do so, use the compass to measure the azimuth heading (that is easy to do with wire mesh dishes, as you can simply stand behind the dish and use the feedhorn support as a pointing guide). Next, use the inclinometer to measure the elevation heading at the dish's back plate. Repeat the procedure for every satellite that the TVRO owner can view. When you are done, you should have a set of readings that looks somewhat like the one shown in Table 1.

Once we have the headings to the satellites from our location, we can use that information to determine if our selected dish site is appropriate. To do that:

- Stand in the selected spot.
- Use a compass to determine true north, as previously described. True south will be 180 degrees from true north. To make things easier, use stakes to mark out a line from true north to true south.
- Using the information for our hypothetical location, our chart tells us that Westar 4 is located on a true bearing of 214.4 degrees. Use a simple plastic protractor (the type found at a drugstore school-supplies counter), laid on the ground, or a compass, to determine where 214.4 degrees is from our spot (remember, true north is 0 degrees, true south, 180 degrees). Face in that direction, and with the inclinometer temporarily mounted on a short piece of lumber such as a 1 × 2 (make sure that the piece is straight) tip the 1 × 2 plus inclinometer upward until it reads approximately 34 degrees.
- If you can sight along the line indicated by the inclinometer and not see anything but sky (assuming, of course, that you are facing in the proper direction), then your site will be fine for your dish (see Fig. 3).

Now, what kind of changes can you expect if you don't live in or near our selected location (Albany, New York)? Obviously the satellite belt stays in the same position; so as you move north, south, east, or west from our example location, the apparent position of that belt in the sky is going to change.

There are several rules of thumb that apply and a look at Table 2 will help show how those rules of thumb are applied.

- The farther south you live, the higher and higher the satellites appear in the sky (the converse of that being that the farther north you go, the lower they appear in the sky).
- Satellites due south of you will always

TABLE 1—ELEVATION AND AZIMUTH HEADINGS

Satellite	Orbit Location	Elevation	Azimuth
RCA F1R	139° W	9.4°	252.4°
Galaxy G1	134° W	12.3°	249.0°
RCA F3R	131° W	15.1°	246.0°
Comstar D3	128° W	17.1°	243.6°
ANIK D1	105° W	31.4°	221.4°
Westar 4	99° W	34.3°	214.4°
Westar 3	91° W	37.5°	204.1°
RCA F4	83° W	39.5°	193.1°
Galaxy G2	74° W	40.4°	178.5°

TABLE 2—LOOK ANGLES

	Concord, NH (43.2N, 71.5W)		Port Au Prince, Haiti (19N, 72W)		Pratt, KS (37.7N, 98.7W)		Mexico City, DF (19.4N, 99.1W)	
Satellite	Elev.	Azimuth	Elev.	Azimuth	Elev.	Azimuth	Elev.	Azimuth
F1R/139 W	8°	254°	13.2°	262°	29.6°	234°	39.7°	249°
G1/134 W	11.6°	250°	18.1°	260°	33°	229°	44.6°	245°
F3R/131 W	13.7°	248°	21°	259°	35°	225°	47.4°	243°
D3/128 W	15.8°	245°	24°	258°	37°	222°	50°	240°
AD1/104 W	30.9°	223°	47.4°	243°	45.6°	188°	67°	195°
W4/99 W	33.4°	217°	53°	236°	46°	180°	67.7°	180°
W3/91 W	37°	207°	59°	227°	45°	167°	66°	157°
F4/83 W	39°	196°	64.4°	211°	43°	155°	61.2°	139°
G2/72 W	40°	181°	67.6°	180°	38°	140°	52.1°	123°

be highest in the sky (ie. be of the maximum elevation). Satellites significantly southeast or southwest of you will have the lowest elevation

- The most difficult satellites to receive are those that are located very close to your own horizon (ie. at elevations of less than 15 degrees). We'll see why, shortly.

Table 2 shows the subtle changes that take place when two locations at the same longitude but at differing latitudes wish to receive the same satellites. For example, both Port Au Prince (Haiti) and Concord (New Hampshire) happen to be near 72 degrees west longitude. But the look angles, particularly the elevation, vary significantly between the two—to RCA F1R, for example. From Concord, the elevation is 8 degrees (barely above the horizon), and the azimuth is 254 degrees. From Port Au Prince, the same satellite has an elevation of 13.2 degrees, and an azimuth of 262 degrees.

What about locations that are farther west? Let's consider the look angles from

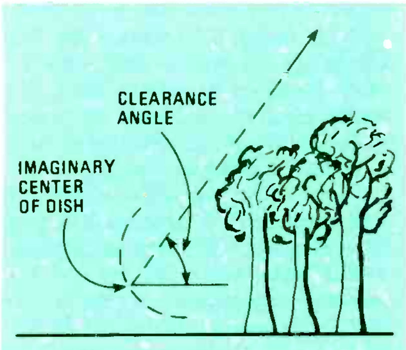


FIG. 3—WHEN SELECTING A SITE for your dish, be sure that there are no obstacles between the dish and any satellites that you wish to view.

Mexico City (19.4 north and 99.1 west) and Pratt, Kansas (37.7 north and 98.7 west). Again from Table 2, from Mexico City, the look angles for F1R are 39.7 degrees elevation, and 249 degrees azimuth. From Pratt, those angles are 29.6 degrees and 234 degrees, respectively. As you can see from the preceding, satellites appear higher in the sky at longitudes that are closer to their own. On the other hand, at greatly different longitudes, the satellite appears closer to the horizon. When you reach a point around 5 degrees elevation (ie. your antenna would only be pointed up by 5 degrees), you begin to have special problems with satellite microwave reception. In particular, noise problems created by the earth itself can become severe, since the antenna is now pointing so low to the earth that it is barely skimming over the distant horizon.

So special and unpleasant circumstances prevail for low look angles. Even if you live on a mountain top and have no obstructions, you may find ultra-low look-angle reception a special challenge.

To review, select a location for your dish where the dish center (not merely the top edge) has a clear, unobstructed view of the satellite belt. If you do not have such a location available (and many do not), you will have to settle for reception of just those satellites that you can "see" from your location.

Up or down

You have two choices for where you will install the dish—on the ground (which is the best choice, if possible) or on a roof. You gain nothing (but potential grief) if you mount your dish anywhere but on the ground when you do not have to. Additional height accomplishes nothing here, since the satellite signal arrives just as strong to a clear-vision site located on the ground as it does to a similar site on a roof.

Sometimes, however, you simply can not "see" the satellite belt (or the part you want) from a ground-located site. Up, on the roof, is the only choice left.

Satellite antennas are available in a number of design configurations. Here are the choices open to you:

- Solid metal, made of either aluminum or steel; there are also solid dishes made of fiberglass. All those tend to be strong, but heavy. They also present a solid surface to the wind, and wind is an important consideration when you are mounting the dish on a roof or tall pole.
- Screen-mesh dishes are lightweight and present less wind loading since some of the wind will blow through the mesh surface. As such, mesh dishes are preferred for roof mounting.

If it is not possible to mount your dish on the ground, there are two options that are available to you. The antenna can be mounted on a metal pole (typically 3 to 5 inch OD, schedule 40, steel), which is in turn supported along the side of a house or building, so that just a short stub protrudes above the roof line. Otherwise, special roof-mounts, which use three or four metal legs to attach to the roof, provide a platform for the antenna itself. The top of such mounts usually end up being a 3 to 5 inch OD pipe, since most antennas have a collar that requires a pipe of that size to slide down over as the point of attachment.

An unsupported steel pipe, no matter how strong, or a tower *can't* be counted on to hold the dish steady and stable in the air. That is important since the dish must stay pointed at the satellite with a stability-accuracy in the region of ⅛ inch in all kinds of weather. The dish cannot sit up there and move about in the breeze (because the pipe is moving slightly under the force of the wind). If it does that, the pictures will fade in and out (mostly out) as the wind moves the dish about ever so slightly (⅛ inch play might seem slight, but in this case it is far too much).

And, a three or four legged rooftop mount has to be installed so that the antenna does not rip loose (taking part of the roof with it!) in a strong wind. Remember that even a mesh antenna is not too different, for windloading purposes, from a sail; and the same wind forces that drive a sailboat will rip and tug at the dish and its mount. People who have attempted to attach rooftop mounts with long lag screws through the roofing material usually come back in a short time to pick up a tangled mess from the yard below (or worse yet, a neighboring yard). About the only acceptable method of installing a three or four legged mount on a roof is to place a steel plate (1/4th inch thick or more) under the roof and use lag *bolts,* rather than lag screws, to ensure that the legs of the mount are attached to and through the steel plate below, rather than merely to the wooden roofing structure—which is certain to give under pressure.

Routing the cables

Your dish will interconnect with the electronics inside your home via some quantity and type of cables. Here is a rundown on some of the cabling that you're liable to find in a TVRO installation.

- A length of coaxial cable (RG-59/U or RG-6/U) that's used to carry the signal indoors from the outdoor mounting LNB/LNC or downconverter.
- A three to five (or more) conductor cable that's used to carry the motor drive voltage to the dish positioner jackscrew, and carry sensor "feedback" signals back inside to the dish positioner control box.
- A piece of RG-59/U or RG-6/U (or in some systems simply a pair of wires) that's used to carry a tuning voltage from the indoor receiver out to the downconverter/LNC (in systems in which only a single frequency is passed from the downconverter to the receiver).
- A two or three conductor cable used to select the polarization of the LNA.

Those are the basics, but some systems use even more cable between the dish site and the inside electronics. Now, how does one route all of that cable safely and attractively—or at least reasonably so? The logical way is to bury the cable underground. There are two ways to accomplish that: use so-called direct burial cable, or route the cable through a length of PVC pipe. Direct burial cables are now available in a single weatherproof sheath or wrapping that contains all of the individual wires or cables needed. With it, you bring indoors only one large cable, rather than several individual cables. But even if you do chose to use that type of cabling, the use of a PVC pipe is recommended. Direct burial cable is, for instance, not immune to damage from a burrowing animal, such as a rodent (those nasty little creatures can really do quite a bit of damage to cables), and such cable is fair game for anyone armed with a shovel or a spade.

Make sure when you select your cable that you take the following points into consideration:

- The length of your cable is important; some of the control wires and the signal (coaxial) cable have specified maximum lengths. If your runs of cable exceed those lengths, line losses may cause your system to fail to work altogether.
- Some areas have special electrical installation codes affecting TVRO's (Los Angeles, for example). You may need an outdoor wiring permit before you install your cables, or the entire TVRO system for that matter; it is best to check before you start to make sure you comply.

Equipment protection

Our look at protecting TVRO equipment will cover two major topics: protecting the equipment that is outside from being damaged by weather or moisture, and protecting any of the electronic equipment from electrical spikes and transients. Let's first see how we can protect outside equipment from the elements.

In any type of system we have at least an LNA/LNB/LNC unit out of doors. It has a signal input end, which is connected to the feedhorn, and a signal output end that is connected directly to the indoor equipment. (If we are dealing with an LNA, we will also have a separate downconverter between the LNA and the indoor equipment.) The connections between the LNB/LNC, or the LNA/downconverter, are made with coaxial cable, as previously discussed. Those cables must be able to withstand weather/environmental conditions such as moisture, heat, cold, dirt, and dust. Moisture, in particular, can be a serious problem.

Moisture of any type *must* be kept out of the system. That means out of the LNA/LNB/LNC, separate downconverter (if used), and any connectors. Special moisture-barrier compounds have been developed; one such is *Coax-Seal* (available at Radio Shack). Those compounds seal any equipment housing or connector/fitting so that it resists moisture penetration.

Moisture and ice present special problems to TVRO dish positioners. The jackscrew drives are apt to freeze when they get coated with ice and snow. (Another, related problem is that snow may fill the dish, and the combined weight of the snow and dish may be more than the drive can move. The solution to that problem, of course, is to make sure that any snow has been cleared from the dish before attempting to move it.)

If you live in an area where ice and snow are common, anticipate winter problems with motor drives. A cage or shield, probably best custom-made by you for your installation, to keep the ice from coating the motor drive and freezing up the system would be a good Saturday afternoon project after the system is installed. And it sure beats missing the Super Bowl in late January because of a heavy ice storm!

As to transient or surge suppression, for safety's sake: All TVRO hardware should be protected with an external surge/transient supressor. Those plug-in devices (available from many sources and often for under $10) will save you countless moments of frustration. Remember, anything in the TVRO system should be so protected, even if the equipment supplier makes his own claim for internal surge and transient protection.

A model system

Of course, no two systems are exactly alike, although each will have the same basic parts and approach to system design. To wrap things up, we'll walk through the elements of a "model" system, including how it is selected and how it is installed. Our model will use a block downconversion scheme, since that seems to be the most popular receiver format for 1985.

Let's start out with the dish, as that is where most people perceive the system to begin. We have already looked at why and where you want to locate the dish, and why certain types of installation procedures may be more attractive than others. So, what else do we need to know about the dish?

Well, for one thing, the dish surface must be highly accurate. As you may know, the surface of most dishes are parabolic shaped so that the weak signals that bounce off them are focused at a single point. That concentrating of signal produces a signal that is strong enough for the following electronics to process. As would follow, then, the more accurate the surface the stronger the signal produced; in other words, the higher the gain. But, how do you select a dish that has an accurate surface? Here are some rules of thumb.

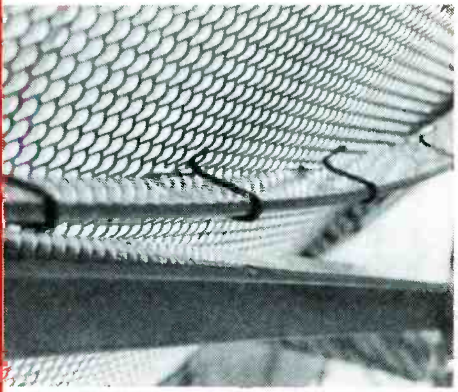
Dishes that are "parabolic both ways" are generally better than dishes that use "flat panels". Parabolic both-ways simply means that the panel sections follow the parabolic curve lengthwise (from center to outer edge) and crosswise (across the panel). Some dishes use flat panel sections that follow the parabolic curve only from center outward to the rim edge. Dishes that use flat panel construction have less gain than those that are parabolic both ways, assuming that all other factors (size, shape-accuracy, etc.) are the same. The difference in gain is on the order of 1 dB, and possibly greater.

Dishes that use ribs with structural support should have greater surface accuracy then those that have ribs that are simply pressed into a parabolic shape. Metal has "memory"—when you stamp, stretch, or force a piece of metal to follow the parabolic curve, the metal wants to regain its original shape (i.e., a straight piece of aluminum or steel). It is possible that with time, plus heat and cold, the metal may lose some of its surface accuracy.

The rear support structure of the dish is very important. It provides rigidity for the entire dish and ensures that it does not warp or bend out of the desired shape.

Unfortunately, most of us are probably incapable of evaluating a back-plate system for its ability to maintain dish shape. Still, a dish minus any form of back-plate system should at best be suspect.

Assembly details vary from dish to dish. We are going to give you some guidelines; but out of necessity, they will



USE PLENTY of clips! In many designs, the mesh surface adheres to supportive under structure only when lashed down with clips. If you use too few clips, the system will not perform to specifications.

be generic rather than specific. When assembling your own dish, follow the instructions supplied with the unit.

Most dishes assemble upside down, and work should be done on a flat surface. All pieces should fit and all bolts should slide through without your having to tug at parts, pry with heavy wedges, or (heaven forbid!) drill new holes for bolts. If you find something does not fit (i.e. holes do not line up), stop and stand back. Before you attack the stuck part with a pry bar or drill, see if perhaps you have misaligned some previously installed part that, in turn, results in the new part not aligning properly.

All name-brand dishes are now "gang drilled," which means that all of the holes are drilled at one time and in one operation. Workman error (misdrilling one hole) is virtually a thing of the past. Before you curse the manufacturer's quality control, check your own!

When assembling the dish superstructure, or in the case of fiberglass or solid metal surface dishes, don't wrench tighten any bolts until all pieces in the "pie" are in place. There is always a small amount of adjustment room in connecting segments together and if you start taking up that adjustment room by wrench tightening before you have all of the pieces in place, you may adjust yourself right out of the tolerances required to slide the last piece into place.

When you do tighten up the bolts with wrenches, follow a pattern. Do the inside (closest to the center or hub) bolts first, for example, and do the bolts opposite one another (across the hub or center) working around the dish (i.e. 12 o'clock and then 6 o'clock, 3 o'clock and then 9 o'clock, and so on). When all inner bolts are tight, then start over with the same pattern on the outer rings of bolts.

When the dish is completed, carefully turn it over so that it faces up. That lets you sight across the dish from the near side to the far side to see if the two align precisely. Now move 90 degrees around the dish and sight across it again. If any of the sides appears to be out of alignment, there is a potential warp in the framework holding the dish. Find out why and fix it, because a warped dish will not work properly.

If your dish is of the screen-mesh variety, don't hesitate to use lots and lots of clips (attaching the mesh to the under support pieces). The clips do more than assure that the screen mesh won't blow away; they force the mesh down to the undercarriage and therein ensure that the surface will follow as closely as possible the desired parabolic curve.

Clips are seldom "fun" to install, and the tendency is to shortcut the job and install just enough to get by. That is a bad mistake, as performance of a screen-mesh dish depends upon forcing the surface into a near-parabolic curve; and that only happens when the mesh actually adapts to the parabolic curved undercarriage-support pieces. Take an extra hour to put in lots and lots of clips and you will be properly rewarded with first-class pictures.

Get plenty of help to lift the dish onto the mount. If the dish gets away from you and falls, it will hit on a edge and bend or warp; probably permanently. If that happens, you'll be best off starting all over again.

The dish mount should include instructions for setting something called declination offset for your locale. That is a special adjustment, usually built into the rear of the arm protruding back from or away from the rear of the dish. It is very important if you want your dish to track the Clarke Orbit belt properly. You will need an inclinometer to set that offset adjustment. Most dish manuals have a chart that lists the declination offset amount for various states or areas.

The feed is that device that mounts on a pole out in front of the antenna. Its job is to gather the reflected signal and pass it on to the rest of the TVRO system. It needs to be adjusted properly if your system is to work. Some feeds allow only one adjustment by the installer; others allow several.

The most basic adjustment is setting the distance away from the dish. The dish manual will tell you the focal length, and that is the distance measured from the center plate of the dish, at the hub, to the edge of the feed that is nearest to the center of the dish. Use a rigid tape measure and slide the adjustable feed pole or pipe to reach that distance.

Another adjustment is the side-to-side centering. That, if available or required with your dish, ensures that the feed is looking squarely at the center of the dish, and therefore all around the dish surface equally.

If you want to make sure that the feed is properly centered (left and right, up and down), take a roll of string or long metal tape measure and measure the distance from the edge of the feed front to the rim

FEED-SUPPORT ARM places the feed and LNA (or LNB/LNC) at the focal point of the dish. The feed arm adjusts in and out to ensure precise setting for maximum signal.

of the dish at several points. The dish should be equal distance from the rim to the feed edge all the way around. Otherwise, the dish is warped and/or is somehow off center.

Tracking the dish

There are numerous techniques for locating your first satellite with your dish; once that's done, assuming everything is working properly, the dish should automatically track through the remaining satellites in the Clarke Orbit belt. The technique we would like to share with you is among the oldest, but it works very well.

Start by making sure your declination (offset) is properly adjusted. Now, using the chart you prepared that shows the elevation and azimuth headings for your location to the various satellites, select a satellite that is fairly low to your west, such as G1, F3R, or D4.

Take the elevation heading (15.1 degrees for F3R from Albany, New York for example) and hand-adjust the antenna's elevation (using the motor drive control if you have one) so that an inclinometer laid against the flat back on the dish reads 15 degrees. Now you have the dish set for one satellite's elevation.

Next, turn on the monitor or TV set (this assumes, of course, all of the electronics is now hooked up—we'll talk more about that later) and set the receiver to either scan (if a scanning feature is available) or a strong signal (such as transponder 7 on F3R, which is ESPN). Slowly rotate the dish on its pipe-stand mount toward the expected azimuth heading for F3R (246 degrees in Albany). With the dish already set at the proper elevation, you will "run across" F3R as you come up on the 246 degree heading. Stop there and temporarily lock down the bolts that tighten the dish-mount collar to the pipe-stand mount.

Now operate **only** the motor control or hand crank, and move the dish east. Place the receiver in scan so that the receiver is changing channels automatically as the dish moves. As the dish's azimuth heading changes, the polar-mount mechanism will also cause the dish elevation to change, raising the dish higher and higher as it tracks to the east. That allows it to track the arc of the Clarke Satellite belt. (We have been assuming all along that you are using a polar mount; other types are available, but they are very difficult to adjust when moving from satellite to satellite.) Along the way, you will note flashes of signal as the dish tracks first past one satellite, then another. Stop when the dish is aimed at F4; transponder 7 (National Christian Network) on that satellite is also strong in most areas.

Now, adjust only the dish's mechanical elevation setting for best picture; do not touch the azimuth adjustment (i.e. don't spin the dish on the pipe mount by loosening the collar to pipe bolts). When you have peaked for best signal, operate the motor drive or hand crank and return to F3R.

Once you are back to that satellite, if the picture is no longer as good as it was when you first found it, adjust only the azimuth by carefully loosening the collar to pipe set bolts and nudging the antenna first one way and then the other. When you have the picture peaked, re-tighten the bolts in the following manner.

- Make each bolt finger tight.
- While watching the receiver signal-level meter (or if none is available, the TV screen, although that's a poor second choice), take a wrench and make one quarter turn on each of the collar tightening bolts in succession. Do not tighten one all the way and then move on to the next, since by doing so, you will slip or slide the collar on the pipe.
- Repeat the sequence, a quarter turn at a time, until all bolts are tight. Do not over-tighten; those bolts typically will break off if you use more than moderate wrench pressure.

Return to F4R and double check that it is still peaked. If necessary, re-touch its signal level by carefully adjusting the elevation adjustment. (If adjustment is needed, it is usually caused by an ill-threaded rod or turnbuckle.)

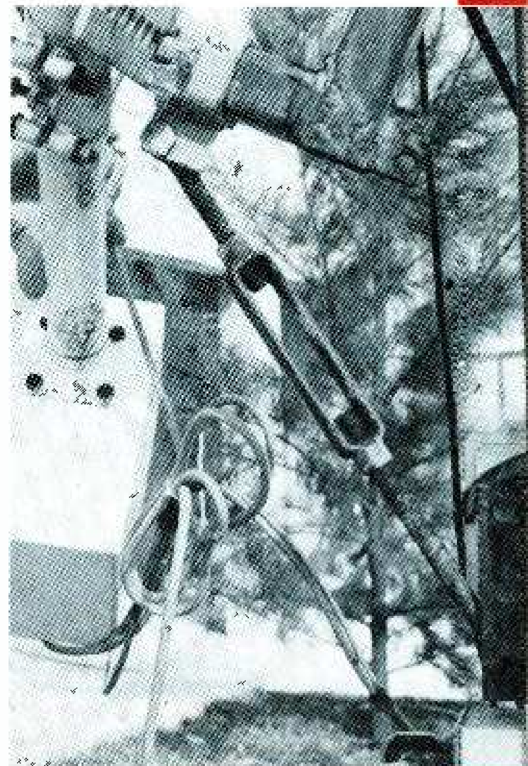
The feed system

The information on centering the feed aside, there is one adjustment required on the feed proper. That is the skew adjustment. Modern satellites (all but Westar 3 are modern by today's standards) transmit 24 channels of possible service. Twelve of those channels are transmitted using vertical polarization, and 12 using horizontal polarization. Polarization, of course, is the technique that makes it possible to cram 24 channels of programming into the frequency space allocated to 12. But that's not our concern here. (For more information on that topic see "All About Satellite TV," in the June 1984 issue of **Radio-Electronics**.) Instead, we'll concentrate simply on how you install and properly adjust the feed.

The feed installs on a plate of some sort at the end of the feed arm or bracket. As we mentioned earlier, the length of that feed arm can be adjusted so that the feed is properly located. In addition, however, the arm (or in some cases, only the plate that the feed is mounted on) rotates. Let's see how that rotation is used to make the skew adjustment.

First of all, install the feed on the plate using the hardware provided. Adjust its distance to the center of the dish as described earlier. Once the system is operating on at least one satellite, tune in a signal. Note, using one of the many satellite TV guides (sometimes, one of those is even included with your dish) whether the transponder you are viewing is horizontally or vertically polarized. Going back to our old friend, F3R, transponder 7, we find that it is vertically polarized (on that satellite, odd-numbered transponders are vertically polarized; even-numbered ones horizontally polarized). Set the polarization control in your system for vertical. Examine the signal displayed on the monitor. Then switch to transponder 8, and re-examine the signal. If automatic polarization switching is built into receiver, the act of changing transponders should also have changed the polarization of the feed and you should have a good picture. If your receiver does not have automatic switching, you will have to set the polarity, via the appropriate control, for horizontal.

Unless you are extremely lucky, there is bound to be some evidence of the transponder 7 signal present. That may include drifting vertical lines, or even two video signals (the one from transponder 8 and a weaker one from transponder 7). If present, we obviously need to remove any sign of the vertically polarized transponder 7 signal. (If you have a receiver with automatic polarity switching, the first step is to temporarily disconnect the polarity control lines between the receiver and the LNB—simply unplug them from the back of the receiver.) To do that, mechanically rotate the feed support arm a touch until any signs of the adjacent transponder disappear. Now, switch back to transponder 7, but *leave the polarity control set for horizontal*. Once again, rotate the feed, if necessary, to make all signs of the vertically polarized transponder 7 signal disappear. Once that's done, tighten the bolts that lock the feed-support arm in place.



ELEVATION is set on this antenna with turnbuckles.

The electronics

Everything we have discussed up to this point applies to any type of TVRO system you might install. The rules are the same for LNA/downconverter, LNB, or LNC systems. The type of system you select will, however, affect what follows.

As we feel that block downconversion (BDC) offers some significant advantages, such as the ability to have multiple receivers without restricting the choice of viewing to a single transponder, we will outline a system that uses that technology. A BDC system consists of the following:

- Some form of signal amplification at the feed (LNA, LNB).
- Some form of frequency downconversion. If you use an LNA, you will need a separate block downconverter. If you use an LNB, the downconverter and LNA are in a single package.
- Cabling from the LNA/downconverter or LNB to the receiver
- Signal splitters that will allow you to route the satellite signals to multiple receivers (if your system calls for that).

The job of the block downconverter is to convert the satellite's 3.7- to 4.2 GHz signals to some lower band of frequencies. Among other things, that allows the connection between the dish and the receiver to be made using common coax, rather than special high-frequency (and very high cost) cable. The output frequen-

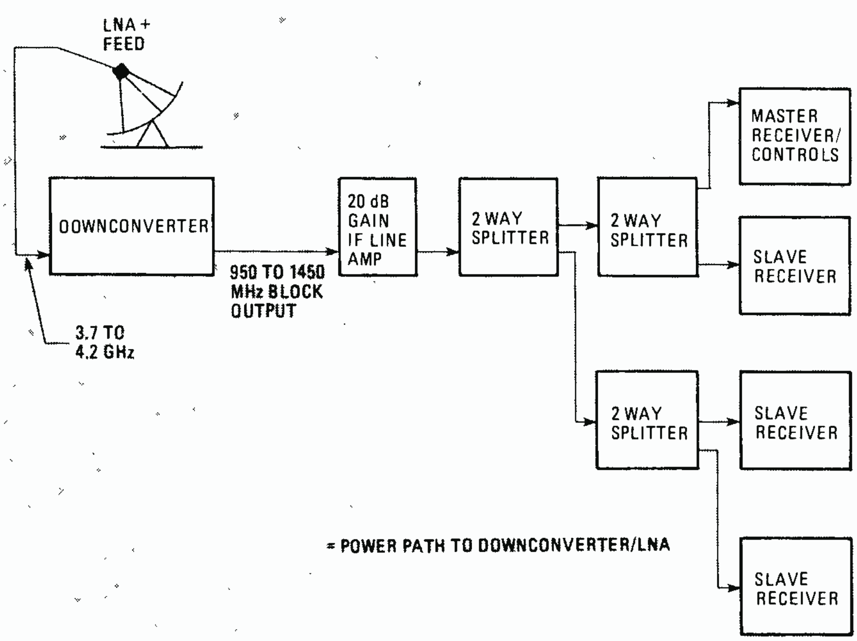


FIG. 4—A FOUR-RECEIVER SYSTEM. Use of the line amplifier ensures that signal levels will be sufficient to overcome any line loss or the loss caused by the splitters.

cies of a block downconverter varies by manufacturer, and range from 270-to-770-MHz to 1140-to-1640-MHz, but all have one thing in common: They all use a 500-MHz band of frequencies, such as 450 to 950 MHz. That is because, in the block downconversion systems, all signals in the 500-MHz input band (4.2 GHz − 3.7 GHz = .5 GHz = 500 MHz) are output to the receiver. Thus, the output band is a faithful reproduction of the input band, only lower in frequency.

Even though the output of the downconverter is much lower in frequency than the input, it is still high enough for line loss to become a significant problem, especially at the high end of the range of output-frequency bands used. The trick, then, is to ensure that each receiver in the home system receives adequate signal strength from the block downconverter. That factor must be considered when planning your system. Also, in a multiple-receiver setup, the individual receiver locations should be isolated from one another to ensure that there is no unwanted interaction between those units.

Neither problem is really anything unique to satellite TV. They've all been faced and solved by CATV and MATV operators.

There is, however, an important difference. In setting up a home distribution system for satellite TV, we cannot simply march into our local parts supplier (such as Radio Shack) or a local CATV supply house, and purchase the components we need. That's because the frequencies used in satellite TV are generally higher than those used for cable or broadcast TV. Thus, since the signal splitters, taps, and so on, generally available from the above mentioned sources, are designed for use at lower frequencies, they will work poorly, or not at all, for our application. Fortunately, appropriate equipment, intended specifically for satellite-TV applications, is made by several manufacturers, and should be available from your installer or dealer.

Loss and gain

Receivers in a satellite system are categorized as masters and slaves. The difference is that the master receiver, which should be located where there is the most TV traffic, controls certain functions for the entire system, such as satellite selection and polarization selection.

Power for the LNB (or LNA and block downconverter) comes from the master receiver and is usually supplied via the same coaxial cable that carries the output from the downconverter indoors

In satellite TV "lingo" the downconverter is labeled the *headend*, or more simply, the point where the signals originate. The downconverter has some output level, specified in dBmV, where 0 dBmV is 1 millivolt (measured across a 75-ohm coaxial cable). A typical signal level from a block downconverter is +10 dBmV.

That +10dBmV signal has to be shared between each of the receiver locations. (The typical satellite receiver requires a minimum input signal level of 0 dBmV.) There are two approaches to that. For larger systems, a tapped trunk approach, similar to that used by cable companies is the best route to go. For a relatively small system (4 or fewer receiver locations), as shown in Fig. 4, the splitter approach is recommended, since it makes slightly better use of the available signal levels. In Fig. 4, we show a system with two receiver locations on the ground floor, and two receiver locations on the second floor. The connection from the downconverter to the house is made using a single length of RG-6/U. At the entry to the house, we have a two-way splitter; between the downconverter and the splitter we also have a line amplifier, but let's ignore that for now. The splitter splits the signal into two "legs". One of those legs, as we said before, feeds the two downstairs receivers. To do that, the signal is fed to a second two-way splitter. One output from that splitter feeds the master receiver, while the other goes to the first-floor slave. (Note that the control signals and power are fed from the master receiver to the LNA/downconverter.) Meanwhile, the second leg is once again fed to a two-way splitter whose outputs are used to feed two upstairs slave receivers.

While we've just outlined what looks to be a very efficient small distribution system, can we be sure that it will work as intended? To answer that, we have to keep some points in mind.

- The downcoverter output is approximately +10dBmV (though that can vary, so check the manufacturer's specifications for your unit).
- The minimum acceptable input level at each receiver is 0dBmV.

From the above, it appears we can sustain about 10dB of loss before we run into problems. That loss will come from two sources: the splitters and the cable. Turning first to the splitters, there are two between each receiver and the downconverter. The typical two-way splitter has 4.0dB of "loss." (Actually, only 1 dB is really lost, the balance of the 4 dB is

(continued on page 93)

TABLE 3—CABLE LOSS

Top end frequency	Cable type	Loss per 100-feet
770 MHz	RG-6/U	6.0 dB
770 MHz	RG-59/U	7.5 dB
950 MHz	RG-6/U	7.0 dB
950 MHz	RG-59/U	8.8 dB
1450 MHz	RG-6/U	9.5 dB
1450 MHz	RG-59/U	11.0 dB
1640 MHz	RG-6/U	10.1 dB
1640 MHz	RG-59/U	12.0 dB

All About OPTOCOUPLERS

Interfacing digital signals to real-world devices has always been a difficult task. But optocouplers can help make it easy!

DANIEL M. FLYNN

HOW OFTEN HAVE YOU WANTED TO INTERface a logic circuit to real-world devices that operate from an AC source or a high DC voltage? That interfacing problem can be overcome in many ways. But perhaps the best way is to use an *optocoupler*. Optocouplers have a lot to offer: electrical isolation, logic-circuit compatibility, small size, and high reliability.

Optocouplers can be used in applications that require electrical isolation—when the low DC output of a logic circuit is used to control an AC motor. Since a logic circuit is incapable of delivering an AC voltage, and AC induced in the logic circuit can cause all kind of trouble, the motor and the logic circuit must be electrically isolated. And that's where the optocoupler really comes in handy.

An optocoupler might be used in applications where the high-level output of a metering device is fed to a microprocessor-controlled circuit to automatically start or stop operation at a predetermined point. (Consider a robotic assembly line, for example.)

In this article, we'll look at several optocoupler circuits that may be used to interface logic circuits to the "real world," or to interface any low-voltage circuit to one that operates on higher voltage. But before we do that, we should first take a closer look at what optocouplers are and discuss their parameters.

Optocoupler basics

The optocoupler (also called optoisolator or photocoupler) is a single component consisting of a light source and photodetector. The two elements are isolated from each other by a transparent insulator, and the assembly is completely enclosed in an opaque package.

The light source for most optocouplers is a gallium arsenide (GaAs) IRED (*I*nfra*R*ed *E*mitting *D*iode). The detector, or output element, may be a phototransistor, photodarlington, light-activated bilateral switch, or light-activated SCR. Figure 1 shows the schematic symbols for those types. Although other types are available, those shown are the most common.

Signals are transmitted between the two electrically isolated elements by means of a light path, or light source. The two elements cannot reverse their roles. And since there are no electrical connections between them, a signal passes through the unit in one direction *only*.

Optocoupler parameters

To successfully design with optocouplers, a clear understanding of their parameters is required. Because we'll be dealing only with low-frequency circuits, we'll define only the DC parameters of those devices. The DC parameters are divided into input, output, and current-transfer ratio.

The *C*urrent *T*ransfer-*R*atio or CTR is the ratio of the input current to output current of an optocoupler (at a specified bias). It is often represented by η. That value depends on the efficiency of the IRED and the spacing between input and output elements. The area, sensitivity, and gain of the detector also play a role.

The DC input parameters define the electrical parameters of the IRED. They are: I_F, diode forward current; V_F, diode forward voltage, and V_R, maximum reverse voltage. (See Fig. 2.)

Because the DC output and transfer parameters differ depending on the type of detector element used by the optocoupler, we'll list and define them separately according to the detector.

Phototransistor- and photodarlington-type optocouplers work on the same principle. The collector-to-base junction is enlarged and works as a reverse-biased photodiode controlling the transistor. That is, radiation striking the junction generates electron-hole pairs, which are swept across the junction by the field developed across the depletion region. The parameters for the photodarlington and phototransistor types are:

- I_C, maximum continuous collector (output) current
- $V_{(BR)CBO}$, maximum collector to base breakdown voltage
- $V_{(BR)CEO}$, maximum collector to emitter breakdown voltage
- $V_{(BR)ECO}$, maximum emitter to collector breakdown voltage

Optocouplers that use light-activated bilateral switches in the output are de-

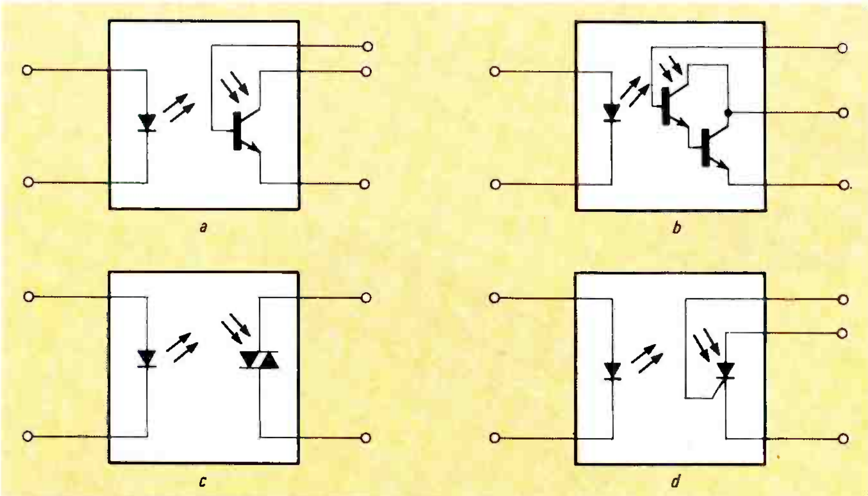


FIG. 1—MOST COMMON OPTOCOUPLERS: ***a*** **has a phototransistor output;** ***b*****, a photodarlington;** ***c*****, a light-activated bilateral switch, and** ***c*** **has an SCR output.**

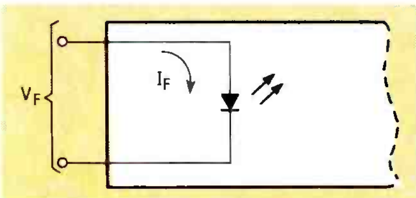


FIG. 2—THE INPUT ELEMENT of most optocouplers is a gallium arsenide (GaAs) IRED.

signed for applications that require isolated triac triggering, low-current isolated AC switching, and high electrical isolation. For that type of device the parameters are:

- $I_{T(RMS)}$, maximum on-state RMS current
- V_{DRM}, maximum repetitive off-state output terminal voltage
- V_{TM}, peak on-state voltage.

Light-activated SCR optocouplers are designed for applications that require high electrical isolation between low-voltage circuitry (like those using IC's) and the AC line. The parameters for the SCR devices are:

- $I_{T(RMS)}$, maximum on-state RMS current
- V_{DRM}, maximum repetitive off-state output terminal voltage
- V_{RM}, maximum reverse voltage

The transfer parameters of an optocoupling device (as mentioned above) is the measure of the ratio of current transmitted between the input and output elements. For phototransistor and photodarlington type units, the parameters are:

- CTR (η), ratio (in percent) of the minimum high collector output-current to diode current at a given V_{CE} and I_F.
- $V_{CE(sat)}$, the collector-to-emitter saturation voltage

For light-activated bilateral switch and SCR types:

- I_{FT}, maximum IRED trigger current required to latch (trigger) the output
- I_H, holding current required for the output to remained latched

The specifications for three optocoupling devices—4N33, 4N26, and MOC3010—are given in Table 1, Table 2, and Table 3 respectively.

Voltage level shifters

When a logic circuit is required to accept inputs from the real world, it is often necessary to shift the voltage level of an input signal to 5-volt logic levels. If the input is a DC signal, it can be interfaced to the logic circuit using an optocoupler without electrically tying the two together (i.e., the two circuits do not share a common ground.)

The advantage to that is that any noise or voltage spikes on the signal-circuit ground are not directly impressed on the logic-circuit ground. An optocoupler can also be used to convert AC signals to 5-volt logic levels, while isolating the logic circuit from the high AC voltage.

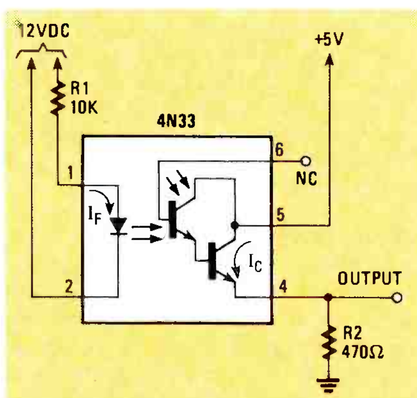


FIG. 3—THIS CIRCUIT MAY be used to trigger a TTL gate input.

Figure 3 shows one optocoupler application where a 12-volt DC (V_{IN}) input is converted to 5-volt logic levels. Here we see a circuit using a 4N33 optocoupler. (Specifications for that device are given in Table 1.) The 12-volt input causes the output of the optocoupler to go to a high logic level. In addition, any common-mode noise is rejected because of the optocoupler's diode input.

When a 12-volt signal is presented to the input, current flows through R1 and the IRED. That current lights the IRED, and the light striking the photodarlington's collector-to-base junction causes it to turn on. The photodarlington output is used here because its large CTR value allows enough current to pass through resistor R2 to develop the required voltage at the output for a logic 1. The output signal can now be used to drive a logic-gate input.

Removing the 12-volt DC signal turns the photodarlington off, and R2 pulls the output low. (In low-speed switching circuits, the base input of photodarlingtons and phototransistors typically remain unconnected. However, high-speed circuits use the base input to increase the switching speed of the device.)

When designing similar circuits for various DC-input levels, remember that

GLOSSARY OF OPTOELECTRONIC TERMS

Bandgap (electronic)—the potential difference between the valence and conduction bands, which determines the forward voltage drop and frequency of light out of a diode.

Current transfer ratio (electronic)—the ratio of input current to output current at a specified bias of the optocoupler.

Dark current (electronic)—the leakage current of a photodetector with no incident light, usually I_{CEO}.

Detector (radiometric)—a device that changes light energy (radiation) to electrical energy.

Effective irradiance (electronic)—IR perceived by a detector.

Emittance (radiometric)—power radiated per unit area from a surface.

Emitter (radiometric)—a source of radiation.

Infrarad (photoelectric)—radiation of longer wavelength than normally perceived by the eye; i.e., .78 to 100 micron wavelengths.

Irradiance (radiometric)—radiated power per unit area incident on a surface, broadband analogy to illumination.

Isolation voltage (electronic)—the dielectric withstanding voltage capability of an optocoupler under defined condition and time.

Light current (electronic)—current through a photodetector when illuminated under specified bias conditions.

Optocoupler (electronic)—a single component that transmits electrical information between a light source and a light detector, which are not electrically connected; also called optoisolator or photocoupler.

Photoconductor (electronic)—a material whose resistivity is a function of the radiation level falling on it.

Source (radiometric)—a device that provides radiant energy.

the value of R2 is determined by the input parameters of the logic gate being fed. The value of R2 given by:

$$R2 < V_{IL}/I_{IL}$$

where V_{IL} is the low-level input, gate voltage and I_{IL} is the low-level input, gate current.

The value of R1 is found by first solving for I_C (collector current):

$$I_C = V_{IH}/R2$$

where V_{IH} is the high-level input to the driven gate and R2 is resistance in ohms. Next, solve for I_F (diode forward current):

$$I_F = I_C/\eta$$

where η is the CTR of the optocoupler. To find the CTR, go to the specification sheet in Table 1 and look under the heading I_C for the coupled parameters. From that we get:

$$\eta = I_C/I_F = 50/10 = 5$$

Now the nominal value for R1 is given by:

$$R1 = (V_{IN} - V_F)/I_F$$

As an example, let's calculate the values of R1 and R2 for Fig. 3, assuming that the driven logic gate is a standard 7400 series. For that type of device, the input parameters are: V_{IL} = .8 volt, V_{IH} = 2 volts, and I_{IL} = −1.6mA. Therefore, the value of R2 is given by:

$$R2 < V_{IL}/I_{IL} = .8/(1.6 \times 10^{-3}) < 500$$

Now it can be seen that R2 is chosen to be the largest common resistor value that is less than 500, which is 470 ohms. Using the value of R2, solve for the collector current:

$$I_C = V_{IH}/R2 = 2/470 = 4.3mA$$

where 2 is the high-level gate input voltage and 470 is the value of R2 in ohms. The value of I_F is found from:

$$I_F = I_C/\eta = 4.3/5.00 = 1.0mA$$

Now look up I_F under the input heading and I_C under output. Since neither of the calculated values exceed the maximum ratings of the 4N33, we can now solve for R1:

$$R1 = \frac{V_{IN} - V_F}{I_F} = \frac{12 - 1.2}{1 \times 10^{-3}} = 10.8K$$

The closest common resistor value to the one calculated for R1 is 10K.

Decreasing the value of R1 increases the loading effect on the signal source and decreases the transfer efficiency. For instance, in a similar circuit with R1 chosen to yield a I_F of 20mA, the current-transfer ratio is only 46%.

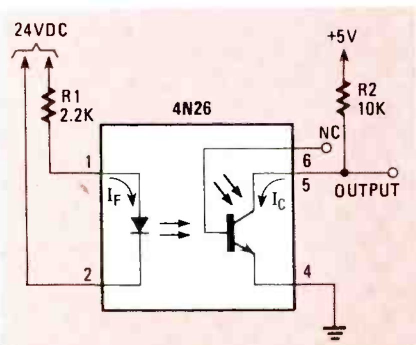


FIG. 4—THE BASE CONNECTION OF the 4N26 is used to increase switching speed.

TABLE 1
4N33 SPECIFICATIONS

		Minimum	Typical	Maximum	Units
Input	I_F			80	mA
	V_F (I_F=10mA)		1.2	1.5	V
	V_R			3	V
Output	I_C	30		100	mA
	$V_{(BR)CBO}$	30			V
	$V_{(BR)CEO}$	30			V
	$V_{(BR)ECO}$	5			V
Coupled Parameters	I_C (I_F=10mA, V_{CE}=10V)	50			mA
	$V_{CE(sat)}$ (I_F=8mA, I_C=2mA)			1.0	V

TABLE 2
4N26 SPECIFICATIONS

		Minimum	Typical	Maximum	Units
Input	I_F			80	mA
	V_F (I_F=10mA)		1.1	1.5	V
	V_R			3	V
Output	I_C			100	mA
	$V_{(BR)CBO}$	70			V
	$V_{(BR)CEO}$	30			V
	$V_{(BR)ECO}$	7			V
Coupled Parameters	CTR (I_F=10mA, V_{CE}=10V)	20			%
	$V_{CE(sat)}$ (I_F=50mA, I_C=2mA)		.1	.5	V

TABLE 3
MOC3010 SPECIFICATIONS

		Minimum	Typical	Maximum	Units
Input	I_F			50	mA
	V_F (I_F=10mA)		1.2	1.5	V
	V_R			3	V
Output	$I_{T\ (RMS)}$			100	mA
	V_{DRM}			250	V
	V_{TM} (I_T=100mA)		2.5	3.0	V
Coupled Parameters	I_F		8.0	15	mA
	I_H		100		µA

The circuit in Fig. 4 converts a 24-volt input, V_{IN}, to an inverted 5-volt output. That is, a high input causes the output to go low. When a 24-volt signal is present, current flows through the IRED, and the phototransistor conducts. Because the output of the device is taken at its collector, the input to the logic gate is low.

When the input signal is removed, the phototransistor turns off and R2 pulls the output high. The 4N26 is used here instead of the 4N33 because of its lower $V_{CE(sat)}$ value. Table 2 shows the specifications for the 4N26.

The resistance of for R2 is not critical. A nominal value for R1 for any input voltage (V_{IN}) level is given by:

$$R1 = (V_{IN} - V_F)I_F$$

where

$$I_F = \left[(V_{CC} - V_{CE(sat)})/R2 - I_{IL}\right]/\eta.$$

The I_F value guarantees that the phototransistor will saturate. The value of R1 when V_{IN} is 24 volts is easily found. Let's say that the driven gate is once again a 7400 series TTL. Since R2 is 10K and the gate requires an input current, I_{IL}, of −1.6mA, then:

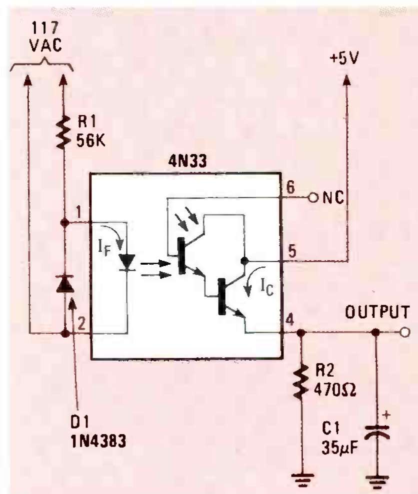


FIG. 5—NON-INVERTING circuit that converts 117 volts AC to to 5-volt logic levels.

$$I_F = \frac{5 - .4}{10,000} + \frac{.0016}{.20} = 10mA$$

Using that value, you can now find the resistance of R1:

$$R1 = 24 - 1.1/10 \times 10^{-3} = 2.3K$$

The closest standard value is 2.2K.

A non-inverting circuit that converts a 117 volts AC to a 5-volt logic level is shown in Fig. 5. With a 117-volt input applied, current flows in the IRED for one-half the AC cycle and in diode D1 during the other half.

During each positive half-cycle, the photodarlington conducts. That causes a pulsating DC voltage to develop across R2, which is then filtered by capacitor C1. The voltage across C1 forces the gate input high. When the AC input is removed, the photodarlington turns off. The voltage across C1 drops as the capacitor discharges through R2. Now, R2 pulls the gate input low.

Load control

When interfacing logic circuits to the real world, a logic gate output is often required to control a 117-volt AC load. The relay circuit of Fig. 6 can be used in such applications. However, many circuit design requirements may *exclude* the use of a relay.

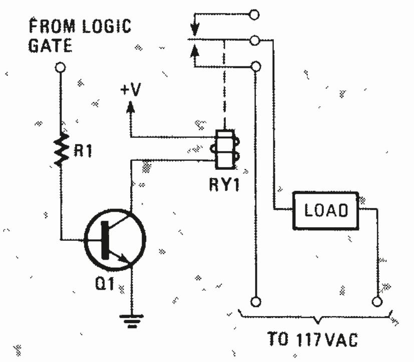


FIG. 6—A RELAY can be used to interface logic gates to real world devices, but circuit requirements may exclude its use.

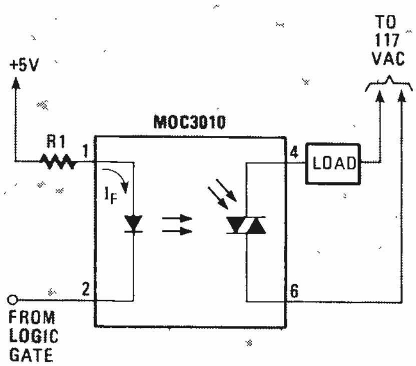


FIG. 7—THIS CIRCUIT MAY be used in applications that have small AC power requirements.

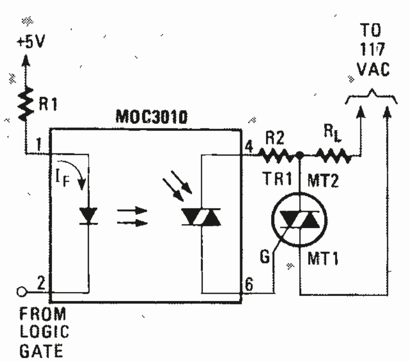


FIG. 8—HERE THE MOC3010 is used to trigger a triac to accommodate larger load requirements.

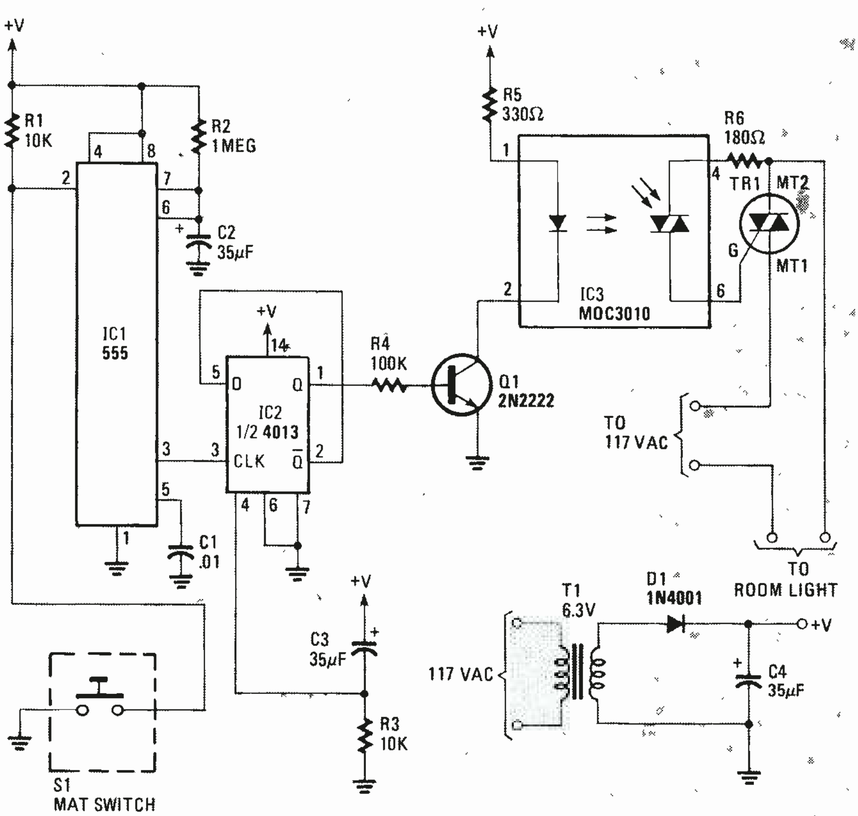


FIG. 9—THE OPTOCOUPLER is triggered by a one-shot to turn on room lights when some one steps on the mat switch, S1.

The optocoupler designs shown in Fig. 7 and Fig. 8 provide electrical isolation and control without the disadvantages of the relay-circuit design. The control circuit of Fig. 7 may be used to drive loads with small AC power requirements. Here a MOC3010 optocoupler is used; its parameters are shown in Table 3.

When the logic-gate output is low, current flows through the IRED of the optocoupler. If I_F is equal to I_{FT}, the bilateral switch output is triggered into conduction. Since the bilateral switch conducts in both directions, power is delivered to the load during the positive and negative halves of the AC cycle. As the output of the logic gate that's feeding the optocoupler goes high, I_F is reduced below I_H of the MOC3010 and the bilateral switch turns off.

The maximum value for R1 is given by:

$$R1 \leq \frac{V_{CC(MIN)} - V_{F(MAX)} - V_{OL}}{I_{FT}}$$

where V_F and I_{FT} are parameters of the optocoupler used and V_{OL} is the low-level output voltage of the logic gate.

Choose the largest resistor value available that's less than the calculated value. Remember, the logic gate must be capable of sinking a current of I_{FT} with some margin of safety. The largest load that the MOC3010 can handle is 12 watts.

The circuit in Fig. 8 overcomes the power switching limitation of the MOC3010. Now we see that the output of the MOC3010 is used to gate a power triac. The value for R1 is calculated in the same way as done for R1 in Fig. 5.

The minimum current required to trigger the triac determines the maximum value for R2, while the power dissipation of the triac gate determines the minimum value for R2. The maximum value of R2 is given by:

$$R2 = \left[(2V_S - V_{TM})/I_{GM}\right] - R_L$$

where V_{TM} is the output parameter of the optocoupler, I_{GM} is the maximum gate trigger current of the triac, and V_S is the AC supply voltage.

Load control application

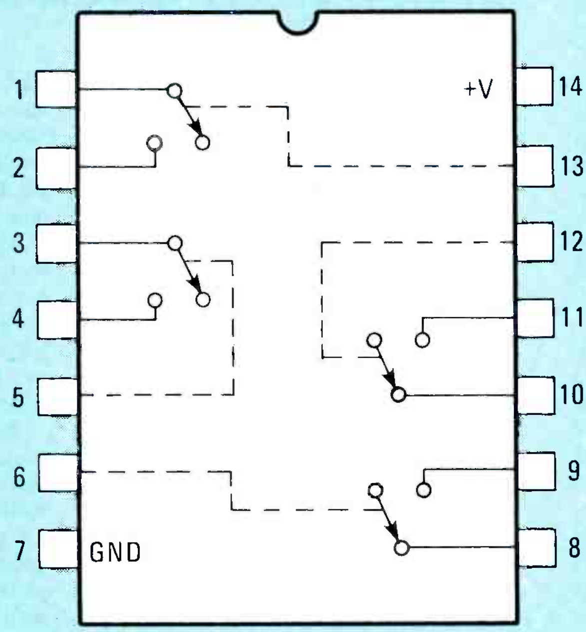
Figure 9 shows a circuit that can turn room lights on and off as the pressure-mat switch, S1, is activated. The 555 timer, IC1, is configured as a monostable (one-shot) to de-bounce S1 and allow time for the person to step off the mat.

The output of IC1 at pin 3 is fed to half of a 4013 dual, D-type flip-flop, IC2-a, so that it is triggered on each clock pulse. When the Q output of IC2-a is high, transistor Q1 conducts. That provides a path to ground for the diode current, and that, in turn, causes the IRED to conduct. The light from the IRED striking the photodetector causes it to turn on triggering TR1, delivering power to the load. **R-E**

Cmos Analog Switches

ROBERT GROSSBLATT

With CMOS switches, you can use digital techniques to control analog signals.



IN THE "OLD" DAYS—WHEN TTL (*T*ransistor-*T*ransistor *L*ogic) was the only game in town—all sorts of hassles used to crop up when you designed circuitry that had both digital and analog elements. Not only were there different voltage requirements for each section, but transients generated by one section of the circuit were a problem for the other section. All sorts of design tricks had to be dreamed up if you expected the circuit to be reliable and glitch-free.

Designing the interface portion of the circuit also presented its own special problems. Schemes of incredibly complex circuitry had to be dumped in the middle of an otherwise sane and orderly design. The benefits you could enjoy by using digital logic to control analog signals were often outweighed by the problems inherent in the design.

Fortunately those days are gone forever. With the introduction of CMOS (*C*omplementary *M*etal *O*xide *S*emiconductor) technology a few years ago, most of the design problems we've been talking about went out the window. The construction techniques used in the design of the chips in that family opened up whole new worlds of possibilities. Because CMOS uses both P- and N-channel MOS transistors, (remember that the "C" in CMOS means *C*omplementary), we aren't limited to having the current flow in only one direction. Everything depends on how we connect up the transistors on the chip. We can see some of the possibilities that appear if we connect the P- and N-channel transistors back to back as shown in Fig. 1.

The simple CMOS switch

When S1, the control switch, is connected to ground, the gate of the N-channel transistor is grounded and the gate of the P-channel (because of the inverter) is at +V volts. Since both transistors are turned off, points "A" and "B" are isolated from each other. (Well, that's not entirely true—because of the leakage current of the transistors.) When we move the control switch to +V, a much more interesting thing happens. The P-channel gate is now grounded and the N channel gate is at +V. Both transistors are turned on and points "A" and "B" are connected to each other through the transistors. Since we're using two complementary transistors, the circuit of Fig. 1 can handle current flow in either direction. The P-channel transistor will conduct in the one direction and the N-channel transistor will conduct in the other. In other words, we can use the circuit to pass either digital or analog signals.

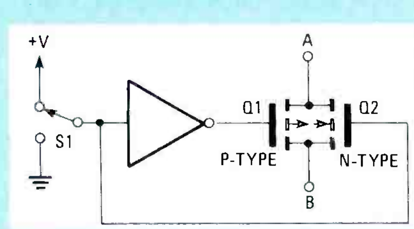


FIG. 1—SIMPLE CMOS ANALOG SWITCH. When S1 is switched to V, a signal path is created between points "A" and "B." When S1 is switched to ground, the path is opened.

The OFF resistance of the circuit will be pretty high since we're essentially looking at a reverse-biased silicon diode. The ON resistance will be low; it's determined by the voltage across and the transistors and their physical characteristics. Although that looks wonderful, let's see what's wrong with it—and what can be done to make it better.

For starters, the ON resistance is going to be on the high side (about 500 ohms) for low-level analog signals. Running audio through that amount of resistance, especially low-voltage audio, can lead to possible termination problems and floating signals. A further problem with the circuit of Fig. 1 is that the resistance is going to change as the voltage changes across points A and B. That's because there's *always* a voltage drop across a transistor and the conductivity of even the world's most perfect transistor will vary somewhat with changes in voltage and frequency.

There's one more problem with the circuit of Fig. 1. Even though the transistors are a matched pair built on the same substrate, they are not *exact* complements of each other. That means that the signal path from point "A" to point "B" won't be exactly the same as the path from "B" to "A." In practical terms, that means that the resistances are going to be slightly different in each direction, and the switch will run the risk of distortion and latch-up if the current flow gets up around the maximum limits of the transistors.

The improved CMOS switch

It's for those and other reasons that the type of switch circuit shown in Fig. 1 was soon referred to as a "simple" switch and the semiconductor manufacturers introduced an "improved" version.

Figure 2 is the schematic of the improved version. At first glance at seems as if there has been quite a bit of change, but a second look will show you that we've simply made a few common-sense additions to the circuit of Fig. 1. Two inverters have been added to the control input of the switch to isolate the control voltage from the voltages being switched. That prevents the possibility of the control voltage being modulated by the voltages across the switch terminals. The high ON resistance of the simple switch has been reduced by adding two new transistors, Q4 and Q5, in parallel with Q1 and Q2. Since they're in parallel, the voltage drop across the two pairs will be less than it was in the simple switch—and a smaller voltage drop means a smaller resistance.

Because the controlling inverter is isolated from the control switch, we can add Q3 to make sure that the switching pairs of transistors stay off when the control switch is connected to ground. Since Q3 is an N-channel transistor, a logic-low at it's gate will turn it on and help make sure that the other transistors are held in cutoff when the switch is opened. Remember that we added the extra switching pair, Q4 and Q5, to lower the voltage drop across the switch. Well, nothing is without a price. The cost of the lower resistance we achieved was the increased possibility of signal leakage through the switch when it's turned off. Even though Q3 goes a long way in helping to lock the other transistors in cutoff, the simple switch of Fig. 1 is still a better choice if your application demands the absolute lowest leakage current when the switch is turned off.

By using the basic principles we've just analyzed, chip designers have come up with an incredible variety of CMOS switches. By combining the switches with other digital circuits, MSI (*M*edium *S*cale *I*ntegration) IC's have been designed that can solve almost any circuit switching problem. On-chip binary counters and decoders allow the use of standard binary addressing to control the switching in a circuit. It doesn't take a great deal of imagination to realize the enormous advantage of being able to easily switch analog signals using digital control lines. Before you rush out and pick up some of those IC's, let's take a look at some of the rules you have to follow when you use them.

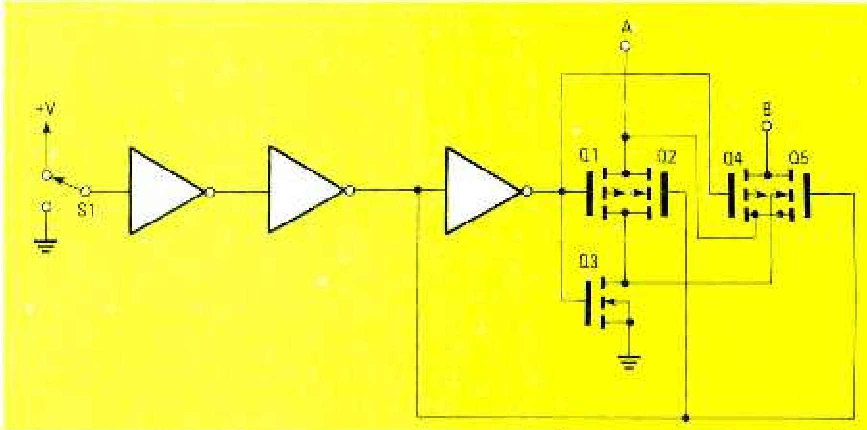


FIG. 2—IMPROVED SWITCH. The ON resistance has been decreased at the expense of a greater signal leakage when the switch is turned off.

1. CMOS technology is used to make analog switches. That means that they are subject to the same sort of damage from static electricity that you can expect with any other CMOS IC. The oxide layer between the gate and channel of a CMOS transistor is extremely thin and can be punctured by even a moderate amount of static discharge. Follow the same handling procedures you would with any MOS device and *never* insert or remove one of those IC's from a circuit that's powered up. It will ruin the chip—and your whole day.

2. The amount of current you can route through the switch changes somewhat with the supply voltage, but it should never be more than 25 mA for improved switches and 15 mA for simple ones. Trying to force more current through the switch will do things like degrading the internal transistors (if you're lucky) or blowing them up (if you're not).

3. There are voltage limits to your input signals. Never allow the voltage swing of the input to go above the supply rail or below ground. That isn't as much of a restriction as it would seem because CMOS IC's can operate over an astonishingly wide power-supply range. If you're sure that the voltage swing of the signals going through the switch in your circuit is going to exceed the range of the power supply, you're going to have to do some designing to meet that restriction. Since CMOS can operate safely at up to 15 volts however, you shouldn't have too much of a problem: It's a fairly simple matter to cut an input signal down to size ahead of the switch and boost it back up afterwards.

4. Never let the control pins float. That's especially true if you have signal voltages always present at the switch inputs. Don't forget that a general rule for all CMOS design is that all inputs have to go somewhere. Remember that the control pins are connected to inverters inside the IC. If the control inputs are floating, the state of the switches will be indeterminate at best and haywire at worst. More than likely, the inverters will bias themselves into linear operation and the whole circuit will start oscillating. Since the inverters will have no clear path to either end of the supply rail, they'll draw a lot of power and you'll be running the risk of blowing up the IC and doing severe damage to the other parts of your circuit.

All those usage rules may make things seem a lot worse than they really are. But in practical terms, CMOS switch IC's are extremely easy to use and provide solutions to design problems by using methods that simply didn't exist before the introduction of CMOS technology.

Table 1 is a listing of some of the switch packages that are available. As you can see, some of the IC's are multiplexer/demultiplexers—switch configurations that are controlled by onboard binary decoders. They're a little bit slower than the plain switch packages, but they come in really handy when you're looking for an easy way to distribute analog data.

Before we examine some of the infinite amount of uses for these IC's, let's examine one consequence of usage rule 3—the input voltage can't exceed the IC's power supply. Although the voltages running around in a digital system are usually within those limits, analog signals are something else. It's perfectly normal for an analog signal to swing below system ground. That is especially possible if the analog signals are being generated by circuitry whose power supply is separate from the digital supply. Figure 3 is a graph that illustrates that problem perfectly. The digital voltage is between 0 and V+ and the analog swing is between +(V/2) and −(V/2). Although the voltage ranges are the same (V volts), it's evident that the difference in the values is going to present a special design problem—or at least one that has to be solved before the switches can be used to process analog data.

The solution is the same as it is with op-amps: The IC has to be powered by a bipolar supply. You're going to have to do something about generating a negative voltage for the IC. That means using center-tapped transformers or some other arrangement to produce the negative

TABLE 1—ANALOG SWITCH IC TYPES

IC type	Switch type	Quantity	ON resistance	Frequency response	Operating speed
4016	SPST	4	500 ohms	40 MHz	25 MHz @12 volts
4051	1 of 8	1	80 ohms	40 MHz	2 MHz @12 volts
4052	1 of 4	2	80 ohms	40 MHz	2 MHz @12 volts
4053	1 of 2	3	80 ohms	40 MHz	2 MHz @12 volts
4066	SPST	4	80 ohms	40 MHz	30 MHz @12 volts
4067	of 16	1	200 ohms	40 MHz	5 MHz @12 volts
4097	1 of 8	2	200 ohms	40 MHz	5 MHz @12 volts
4529	1 of 4	2	300 ohms	35 MHz	5 MHz @12 volts
	or				
	10 of 8	1	300 ohms	35 MHz	5 MHz @12 volts

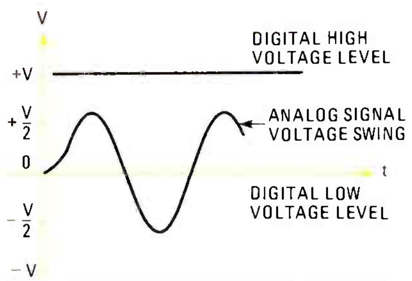


FIG. 3—SITUATIONS WHERE THE ANALOG signal swings below the system ground require that a bipolar supply be used to power the IC.

voltage level. The exact amount of power you'll need from a negative supply will depend on how you're using the switch, the frequency of the input voltage, the output load, and so on, but the current demand will never exceed about 5 to 10 milliamps. Since so little is needed, a center-tapped transformer is really overkill. A more realistic approach is to get below system ground by using some "Mickey-Moused" circuits or even one of the IC's specifically designed for the job, such as Intersil's ICL-7660 voltage converter.

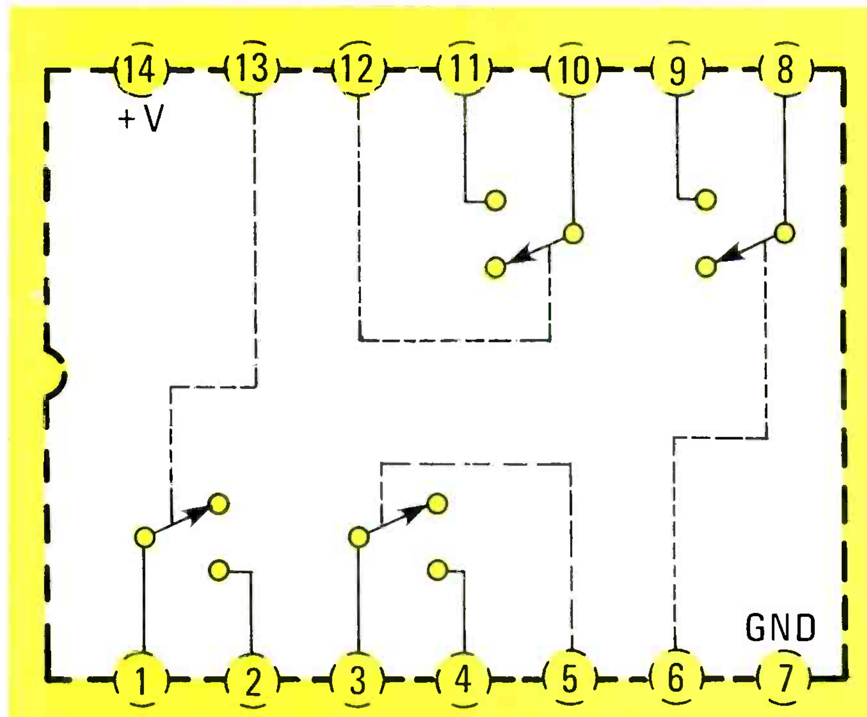


FIG. 4—QUAD ANALOG SWITCH. Functional diagram of the 4016 and 4066 switches.

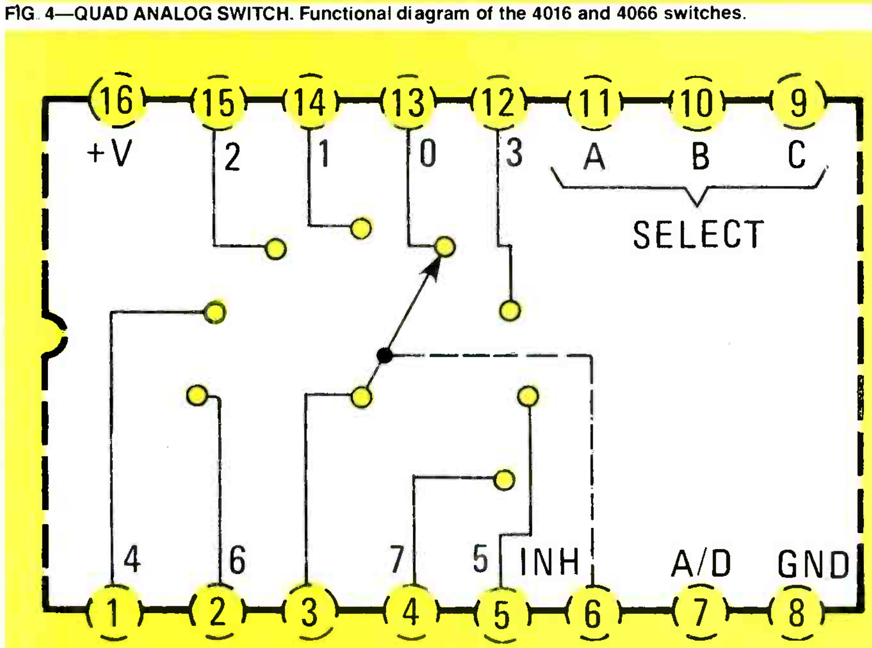


FIG. 5—ROTARY ANALOG SWITCH, the 4051, is essentially the same as its mechanical counterpart.

Some real devices

Figures 4 and 5 show you two of the IC's in the family of analog switches. Since they're typical of the basic types of switches available, understanding them will make you familiar with the other IC's in the series.

The 4016 (in Fig. 4) is a package containing four simple switches exactly like the ones we analyzed. The 4066 is a pin-for-pin replacement containing four improved switches. The switches can be ganged together any way you want to satisfy whatever switching needs you have. A high signal on any control pin will close its associated switch and a low signal will open it.

Aside from the rules and limitations we've already discussed, there's nothing special you have to watch out for when you use this IC. The switches are all independent of each other and the crosstalk between them is very low—isolation is on the order of about 50 dB.

The 4051 (in Fig. 5) is one of the MSI rotary type switches we discussed before. It's a single-pole, eight-position switch and can be used, like its mechanical counterpart, to either select or distribute data. Pin 3 is the center pole of the switch and it will be connected to whatever pole is designated by the three-bit word presented to the weighted select pins (9, 10, and 11). Pin 6 is an enable or inhibit control for the IC—if it's made high the inputs will be disconnected from the output. That's a useful feature because there might very well be times when you want no channel to be connected. Pin 7 gives us an easy way to make the IC usable for both digital and analog applications.

If you're going to use the 4051 to handle only digital signals, you should tie pin 7 to ground. That pin is connected to circuitry inside the IC that takes care of the voltage translation needed to handle analog signals. When analog signals are going to be routed through the chip, you should connect it to the lowest voltage level in your system. That would be the lower limit of the analog voltage swing presented to the chip. In practice, that would probably be whatever negative voltage level you're generating in your system.

Remember that you can't ever let the input signals exceed the voltage range spanned by the supply levels on pin 8 and pin 16. If you connect pins 16 and 7 to +6 and −6 volts respectively, and connect pin 7 to ground, you can handle analog voltages of up to 12 volts and still use 6-volt digital-control signals to select the channel you want selected in the IC.

Even the slowest of the analog switches will operate at 2 MHz with a 12-volt supply. The frequency response of the switches is typically 40 MHz. That means that you can easily switch audio signals and even standard NTSC video signals. Since the propagation times are on the order of about 200 nanoseconds, you're probably thinking that these devices can be used for popless audio switching, remote control of analog signals, and so on.

Digitally controlled gain

Well you're absolutely right. Let's look at two basic examples. Figure 6 shows how you could use a 4066 to digitally control the gain of an amplifier. The amplifier is an op-amp in a non-inverting configuration, and the gain is determined by the amount of resistance in the feedback path.

By putting a binary word on the control pins, we can have any one of 16 possible gain settings that are both precise and repeatable. Obviously that circuit is not the last word in this sort of thing, and we're not limited to using a 4066. We can gang as many switches as we want, use one of the "rotary" switches, or any combination at all. Microprocessor control of things is a real possibility and the range of control you have will be limited only by the width of your data bus.

The advantages of digital gain-control are obvious. Anyone who has fooled around with audio knows the insidious nature of 60-Hz hum from the power lines. As you run more and more lengths of shielded cable, your chances of maintaining a clean signal get less and less. That's in sharp contrast to digital signals: You can grind the digital control lines into the dirt and not upset anything. (Well, almost anything.)

Figure 7 shows you how you can use a 4051 to select the inputs to an amplifier. If you use that sort of arrangement with audio signals, the transition from one channel to another will be smooth, popless, and absolutely undetectable. Notice also

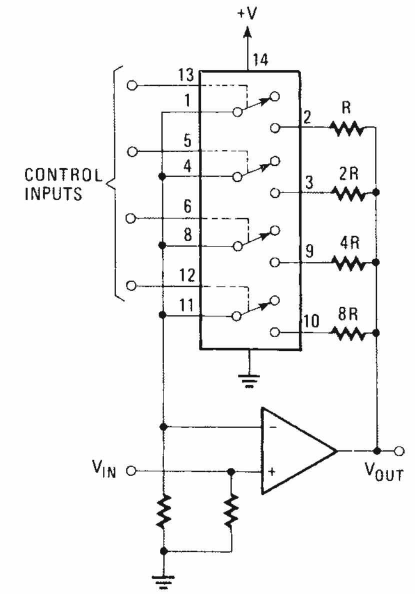


FIG. 6—SIMPLIFIED SCHEMATIC of a digitally controlled variable-gain control.

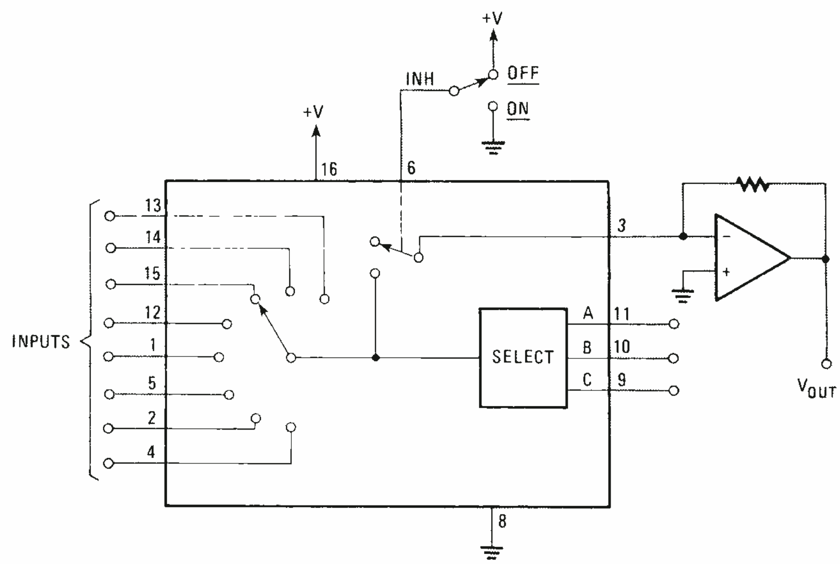


FIG. 7—INPUTS TO AN AMPLIFIER can be switched in any order using the select lines.

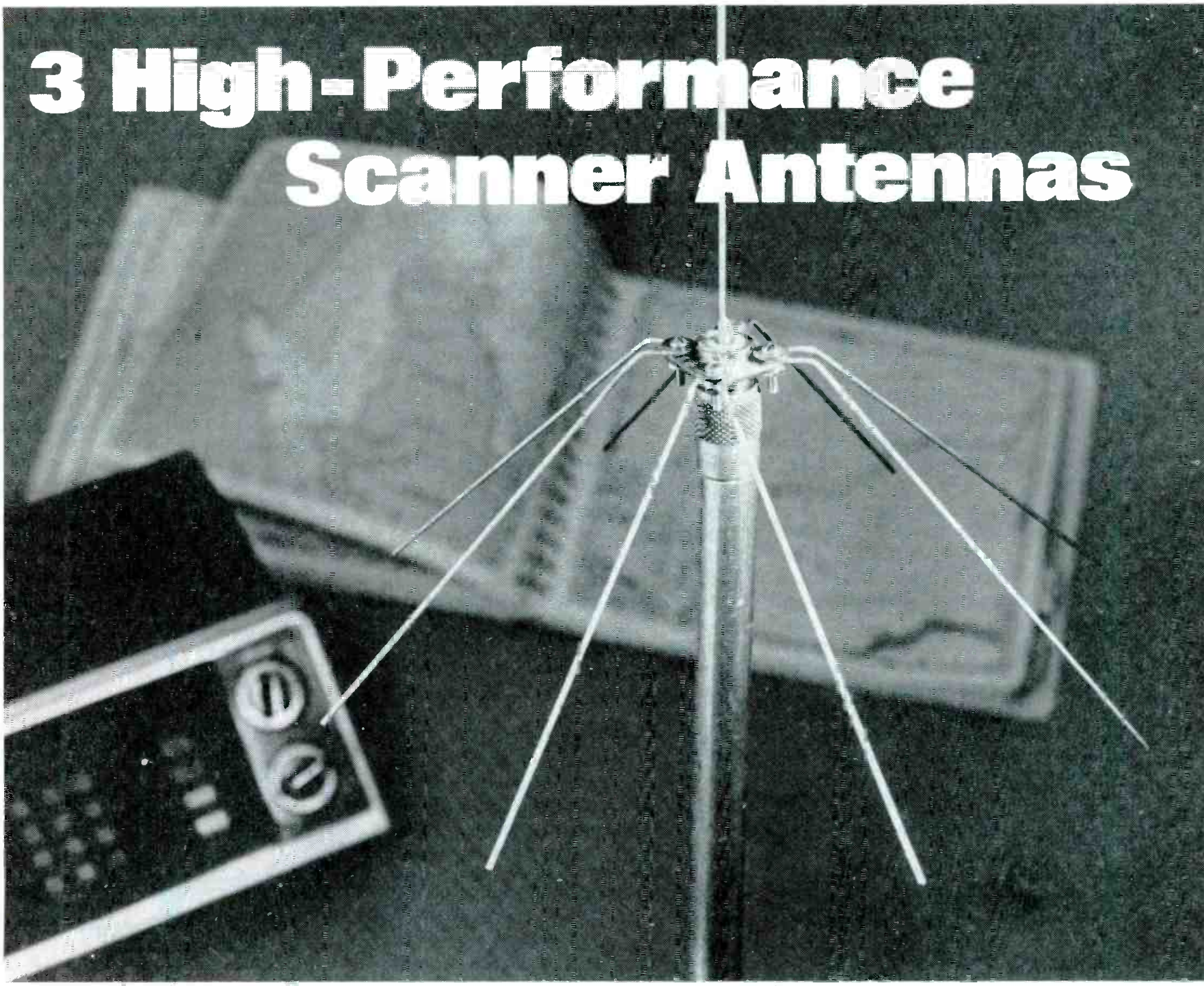
that you don't have to switch channels in any particular order as you do with mechanical switching. You might refer to that sort of circuit as a random-access selector. Since those are analog switches, you can turn the circuit upside down and use it to send a signal to a selected output—in other words, a distribution amplifier.

That isn't as trivial an observation as it may seem. Remember that the 4051 will scan outputs at greater than 2 MHz. That immediately brings to mind a unique sort of distribution amplifier. A little bit of design ingenuity will allow you to use one amplifier to feed eight outputs by scanning the outputs so quickly that there's no noticeable signal loss at any one of them. (That's similar to multiplexing LED displays.) Since the OFF resistance is essentially an open circuit, crosstalk is less than 50 dB, and because CMOS is an inherently noise immune logic-family, that sort of circuit is a real possibility.

The question of video switching is interesting. The analog switches have more than enough speed and bandwidth to handle it. Even the slowest devices can pass frequencies up to 40 MHz and premium IC's can go way past that. I've built video switchers using analog switches and, beyond the normal precautions you take when working with high frequencies, no particular problems showed up. Remember: I'm talking about NTSC video—not un-demodulated broadcast television signals. TV signals would be a bit of a problem because you'd be looking at VHF and UHF signals. You might be able to handle the extreme lower end of the VHF band, but that's about it. Since Channel 2 centers around 58 MHz, you're starting out at the upper limit of most analog switches. And since UHF begins somewhere around 440 MHz, it's out of the question. The best approach is to demodulate those signals before the analog-switch circuitry, and cut the frequencies down to a level more easily handled by the switches

CMOS switches are the digital windows to the analog world. No logic family has ever been able to directly process the signals those IC's were designed to handle. Although they can be used to deal with digital data, their real advantage comes in being able to deal internally with analog voltages. The next time you design circuitry for audio or video signals, using these specialized IC's can save you time at the bench. They'll also help reduce the number of problems with power supplies and provide you with an elegant solution to what used to be an impossibly complicated problem. **R-E**

BUILD THESE



3 High-Performance Scanner Antennas

Are you still using your scanner's built-in antenna? Build one of these custom antennas and pull in those weak signals you've been missing!

LOREN FREBURG

IF YOU'VE RECENTLY BOUGHT A SCANNER/ monitor, you've probably become hooked on evesdropping. You have also probably come to the realization that the skimpy little antenna that screws into the top of the unit has serious limitations. Reception from highway-patrol mobile units may come and go. Fire department transmissions from portable units may be inaudible from just a few miles away. And sometimes you may hear *only* the base station side of a conversation in a neighboring town.

If you've had similar experiences, an external antenna may be just what you need. Not the general-purpose (do-everything-half-way) type, but one designed to be optimum for the frequency you are most interested in, and yet provide good reception on the other frequencies!

There are three limitations to the built-in antenna. First, the height is too low. High-frequency radio waves tend to travel in straight lines, so low positioning limits the antenna's performance. Rooftop mounting allows the antenna to "see" farther because the horizon is more distant. The higher you can get your antenna, the better. Second, the length of the filaments are arbitrarily chosen and possibly too short. A correctly designed antenna is of a particular length. If an antenna isn't made to that particular length then, generally speaking, the longer the antenna, the better. Built-in antennas obviously don't meet that criterion. A third problem with built-in antennas is that reflections from nearby objects upset performance. Anything that is electrically conductive can absorb radio-frequency (RF) energy and then re-radiate it, causing interference or signal drop out. Such re-radiators include any thing metallic from house-wiring to pipes, and even metal picture frames.

A well designed outdoor antenna can overcome all those problems. The three antennas that we'll be describe, *ground plane*, *extended double-Zeppelin* and *coaxial collinear*, offer the best performance, and ease of construction at a low cost. They all share two characteristics: they are vertically polarized (mobile units require vertical antennas) and they're omnidirectional.

There are several public service bands that you're probably interested in. Those bands are shown in Table 1. The bands are divided that way because radio frequencies are widely separated between bands. The frequency determines the physical size of a particular type of antenna. Table 2 shows the typical antenna height of each antenna for a given band.

Antenna theory

Electromagnetic radiation travels at a velocity of 186,000 miles per second (C) in free space or a vacuum, and more slowly through other substances—for example, about ⅔ the free-space velocity through solid polyethylene. (The velocity in a particular medium divided by the velocity in free space is termed the *velocity factor*.)

That radiation travels in a wave-like motion; the distance between successive waves is defined as a *wavelength*. (The symbol for wavelength is λ). Frequency is defined as the number of waves passing a given point in one second. So a wavelength (in miles) is equal to 186,000 miles per second divided by the frequency or number of waves per second.

One wavelength, in miles, is expressed as $\lambda = 186{,}300/f$, where λ is the wavelength in miles and f is the frequency in hertz. Likewise, wavelength can be expressed in meters: $\lambda = 3 \times 10^5/f$, where λ is the wavelength in meters and f is the frequency in hertz.

Because we're working with distance measured in feet and frequency in megahertz (MHz), the formula can be rewritten as: $\lambda = 984/f$, where λ is expressed in feet and f in MHz. For example, a frequency of 984 MHz has a wavelength of one foot. (As the frequency increases the wavelength decreases. The opposite is true as frequency decreases.)

Resonance is another point that we should consider. Resonance is defined as a state in which the natural response frequency of a circuit coincides with the frequency of the applied signal. In other words, it's a condition in which a minimum amount of energy is needed to maintain current flow. That condition exists in an antenna when its length is exactly one-half wavelength ($\lambda/2$) long. Only a small amount of additional energy is needed to overcome losses in the conductor.

Let's take the analogy of a playground swing (a rather crude example of resonance, but it will illustrate our point). If a swing is pushed gently once every pass, its motion is sustained indefinitely with little additional energy. But, if the swing is pushed at a rate that doesn't exactly coincide with its movement, the smooth-flowing motion is interrupted. (You might say that it has met some resistance.) Thus, maximum performance is obtained when the antenna is at, or at least near, resonance.

Before we leave our swing, let's consider polarization from the simplest point of view. Although not a strict mathematical explanation, the similarity gives some idea of its importance. A properly timed push, whether from the back or the side, will maintain motion. However, our swing is designed for front-to-back motion (you might say it's polarized). Likewise, an antenna is polarized. Current should flow along a conductor, not across it.

Antenna impedance is a difficult concept to grasp because it doesn't really exist. It is only the mathematical quantity obtained by dividing the instantaneous voltage by the instantaneous current, which varies all along the antenna conductor. In a theoretical antenna in free space, the current at the end is zero and the voltage is at maximum. Thus, the impedance is seen to be infinite.

At a point on the conductor where the voltage is zero and the current at maximum, the impedance is zero. The importance of antenna impedance becomes apparent when we attempt to transfer energy in an antenna to a feedline and then to a receiver or scanner. Maximum energy transfer occurs when the impedances are matched—ideally, a 50-ohm monitor connected via 50-ohm feedline to the point on the antenna where the impedance is also 50 ohms.

That allows all energy picked up by the antenna to be transferred to the scanner, assuming there are no other losses. The same applies for transmitting antennas, except for power differences. A proper transmitting antenna is a proper receiving antenna, and visa versa.

The radiation pattern of a transmitting antenna is a three-dimensional representation of its relative efficiency in radiating power in different directions, as shown in Fig. 1. (Don't be concerned with the terminology, which appears to be describing a transmitting, rather than a receiving, antenna: The functions and terminology are interchangeable.)

An antenna that radiates equally well in all directions can be represented by a sphere, with the antenna being a point at the very center. Such an antenna, which exists only in theory, is called an *isotropic radiator*.

The fundamental resonant antenna (one-half wavelength long) is called a *dipole* when the feedline is connected to its center. Such antennas radiate energy in a figure-8 pattern, with a tiny hole in the center as shown in Fig. 1-*a*. The dipole runs through that hole.

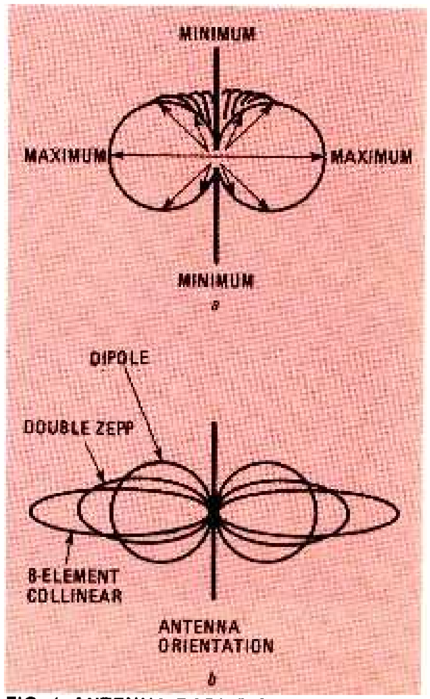


FIG. 1—ANTENNA RADIATION PATTERNS: *a* shows that the radiation pattern of a dipole is most intense at a point perpendicular to its center; *b* compares directional patterns for the three antenna types.

Figure 1-a also shows that maximum radiation (maximum sensitivity in receiving antennas) is in a direction perpendicular to the orientation of the dipole. Moving toward the ends of the dipole, signal pickup is at minimum. The dipole is usually wired at its center because the theoretical impedance is 73.14 ohms, and that is a convenient value to match to a feedline.

The gain of a particular antenna is an expression of the amount of energy radiated (or picked up) in the direction of the highest gain, and compared to a reference antenna. Let's use, for example, the hypo-

TABLE 1
PUBLIC SERVICE BANDS

Band	Frequency Range	Wavelength
VHF-low	30-50 MHz	33 ft. - 20 ft.
VHF-high	118-136 MHz	8 ft. - 7 ft.
	148-174 MHz	6.6 ft. - 5.7 ft.
UHF-low	410-470 MHz	2 ft
UHF-high	470-512 MHz	

TABLE 2
TYPICAL ANTENNA LENGTHS

Band	Ground Plane	Extended Double-Zepp	Coaxial-Collinear
VHF-low	6 ft. + radials	32 ft.	80 ft.
VHF-high	1½ ft. + radials	8 ft.	20 ft.
UHF	6 inches + radials	2½ ft.	6½ ft.

thetical isotropic antenna (which radiates equally well in all directions) as our reference standard. If both the isotropic antenna and a dipole each radiate all of their energy, the dipole will have some gain because its energy is concentrated in fewer directions. Thus, the gain of an antenna is a function of its radiation pattern.

A high-gain antenna has a radiation pattern that's highly directional. Antenna gain is expressed in decibels (dB): $dB = 10 \log P_A/P_R$, where P_A is the power density or field strength of the antenna being compared and P_R is the field strength of the reference antenna. But how do we get a gain with our antenna if we need reception from all directions? We don't really need reception from all directions, just all compass directions. Signals from above or below us are not needed, and that's the key to unlocking better performance.

If the dipole antenna is positioned vertically as shown in Fig. 1-*a*, its radiation pattern wraps around it (like a coil wrapped around a stick) and there is 2.14 dB gain relative to the theoretical isotropic radiator. To obtain more gain the pattern must be compressed, making it flatter and wider. One way to flatten out the pattern is to stack half-wave dipoles and connect them so that the currents are additive (in phase).

Both the extended double Zeppelin and the coaxial-collinear antennas are variations of the stacked-dipole technique. Their radiation patterns are shown in Fig. 1-*b*, along with that of the dipole type. (Note that the ground plane antenna, which is our third antenna type, is simply a dipole that has been modified).

Antenna design

Until now, we've been talking only theory; but, in the real world, there are additional considerations. The antenna diameter itself must be taken into account at the higher frequencies. That's because a "fat" antenna acts electrically as though it were physically longer. Thus, the antenna must be made shorter than theory indicates. Table 3 shows the correction factor that the calculated wavelength must be multiplied by to obtain more accurate results.

Another factor affecting antenna performance is the presence of the ground beneath an antenna, which acts like an "electrical mirror." The reflected RF reaches the antenna later than the signal strike the antenna directly. Those late-arriving signals are added to the first, and either increase or decrease antenna current, depending upon the length of the delay.

That delay depends on the proximity of the antenna to reflective materials like nearby buildings, metal objects, bodies of water, and ground. All have similar reflective properties, and their effect is a function of their conductivity. Because of the complex and often unpredictable nature of reflections, they are best avoided.

TABLE 3
CORRECTION FOR DIAMETER OF ROD OR TUBING

Ratio $\left(\frac{\text{Wavelength}}{\text{Antenna Diameter}}\right)$	Correction Factor
50	0.945
70	0.950
100	0.955
200	0.960
400	0.965
1000	0.970
4000	0.970

One way to minimize ground reflection problems is to make an artificial ground an integral and therefore predictable part of the antenna system. That's an important feature of the *ground plane* antenna.

Design theory must be combined with the available materials to make an antenna. The antennas described here use commonly available materials, and building them requires a minimum amount of tools. The antenna elements themselves are made from brass brazing rods, aluminum tubing, or coaxial cable.

Brazing rods are available from welding supply houses or someone who does brazing (such as auto repair or machine shops). Aluminum tubing can be bought in most hardware stores and home improvement centers. Coaxial cable and connectors can be obtained from electronics supply houses and the miscellaneous materials may be picked up at your local hardware store.

It should be emphasized that when designing an antenna, the dimensions are only a starting point. Use your imagination to combine the measurements with materials that you feel comfortable with or have on hand. Remember, materials can be modified. For instance, two brazing rods are easily soldered together to make longer elements so long as the joint is *first* wrapped with copper wire (see Fig. 2). Likewise, two pieces of tubing may be telescoped if necessary.

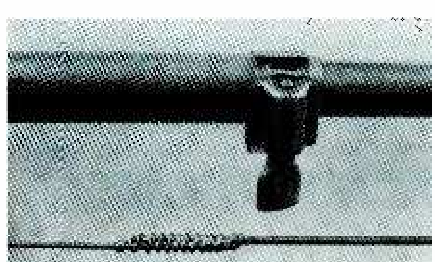


FIG. 2–TWO BRAZING RODS may be soldered together if longer elements are needed.

Ground plane

One of the most common communications antennas is the *ground plane*. (Figure 3 shows how dipole evolves into a ground plane antenna). In Fig. 3-*a*, we have the basic dipole. An artificial ground (ground-plane) replaces the lower half of the dipole in Fig. 3-*b* and functions much like a reflector. It has about 1.8 dB less gain than a dipole, but often outperforms a dipole in spite of that. That's because it is less affected by reflections from the ground, which can cancel out antenna current.

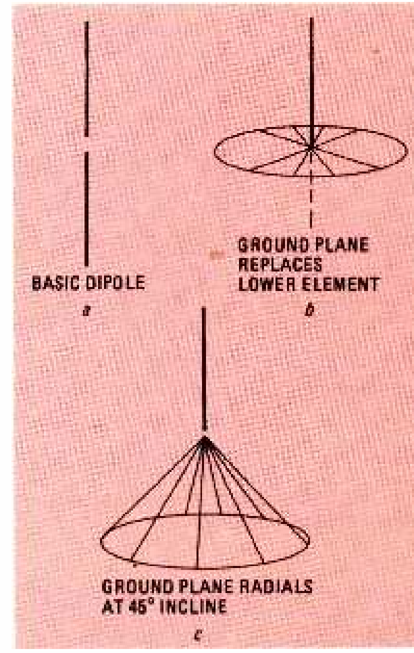


FIG. 3–THE EVOLUTION of the ground plane antenna: *a* shows the basic dipole; in *b*, the lower half of the dipole is replaced by a ground plane, and *c* shows the ground plane bent downward at a 45° angle.

The ground plane itself is usually made of wire extending from the base of the vertical element. The ideal antenna would have a continuous ground, perhaps made from a sheet of copper. A series of wires, or radials, approximates that condition. The more radials used, the closer we approach the ideal.

The wires can be self-supporting if made from a stiff rod or tubing. The impedance of a ground plane antenna is about 30 ohms when the plane is flat. By lowering the radials by 45° (as shown in Fig. 3-*c*) its impedance is made close to 50 ohms, which matches available coaxial cable and typical scanner/monitors. Also, lowering the radials lowers the radiation pattern, which effectively increases its gain.

A ground plane may be made from a coaxial chassis connector and wire. Figure 4 shows how to find the correct length for the radials and antenna element to be mounted on the connector. The antenna element and radials are made from brass brazing rods, which are available in 3-foot lengths and in diameters from 1/16 to 1/4 inch. The rods are fairly rigid, yet may be bent as needed. They're easy to solder, certainly an advantage when elements longer than 3 feet are needed. Use thinner rods for extensions and thicker rods next to the coaxial connector. →

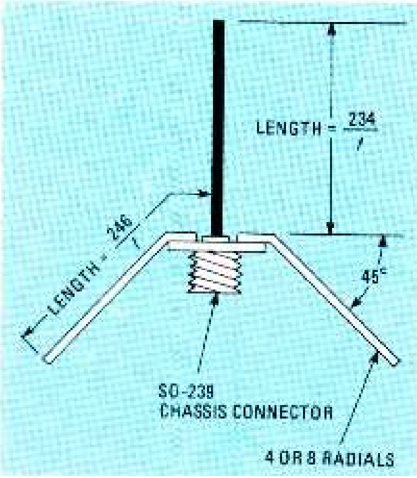


FIG. 4–THE GROUND PLANE antenna is built on a coaxial chassis connector.

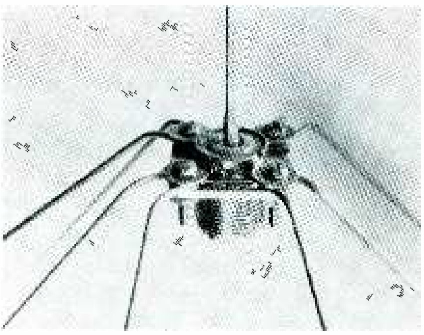


FIG. 5–GROUND PLANE antenna-base; brazing rods form the artificial ground and antenna element.

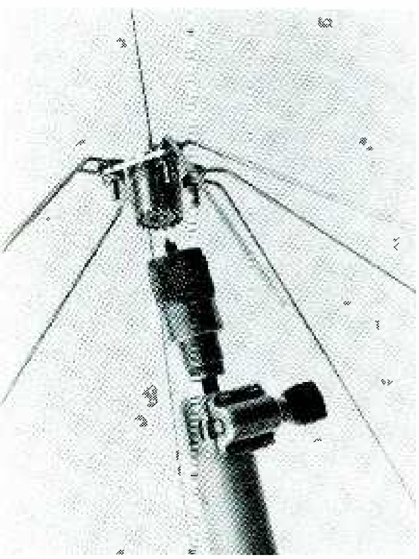


FIG. 6–THE GROUND PLANE antenna's connecting cable is run through the center of the tubing.

The vertical element should be $\lambda/4$ long. Cut the rod about ½ inch longer initially, and do the final cut after soldering to the chassis connector. Note that the ground-plane radials are each 5% longer than $\lambda/4$. That length includes the distance contributed by the base. Again, the final cutting is done after installation.

Don't forget to correct the lengths of the various elements for the diameter of material you're using.

Figure 5 shows how the radials and element are connected. It is best to use eight radials as shown. Four radials will work. but not as well. Bend them downward 45° and space evenly around the fitting. Solder the vertical element to the center pin of the fitting.

Now prepare the mast by making four 1½ inch lengthwise cuts in a piece of tubing. The inside diameter of the tubing should be close to the diameter of the plug (about ¾ inch). The plug will be held in the end of the tubing. Connect the plug to the cable and insert the assembly in the slit end of the tubing, as shown in Fig. 6. Then secure the assembly in place with a hose clamp.

The antenna may now be screwed onto the plug and moved to its final location. The ground plane is easily self-supporting when designed for the VHF (high) and UHF bands. However, when the lengths of the elements are 6 feet, as with the VHF low band, a little wind can really whip those rods around.

That problem is easily solved by adding a little bracing. The radials may be supported by 1 × 1 inch piece wood or lightweight tubing. Support is not needed all the way to the ends, about half to a third of the length should do. The vertical element must be braced with non-conductive material like a wooden dowel, 1-inch square piece of wood, plastic PVC tubing or similar material.

Extended double-Zeppelin

The extended double-Zeppelin antenna is a frequently-used modification of the design originally used in World War II Zeppelins, which is where the antenna got its name. The Zeppelin, or Zepp antenna is a resonant, end-fed antenna with a two-wire transmission line. The design presented here has an antenna element connected to each conductor, hence the name double-Zepp.

In the double-Zepp design, three half-wavelength sections are connected end to end, as shown in Fig. 7. The induced currents in the two outside elements flow toward the center conductor. Any induced current in each of the center $\lambda/4$ sections (phase-reversing stub) flow in opposite directions relative to each other, so their sum is zero.

That means that resulting current in the center section will be due only to the current induced in the antenna itself. When the antenna elements are close together, as shown in Fig. 7–*a*, those elements interact, reducing the total current flow and the gain of the antenna.

That problem is overcome by wider spacing (see Fig. 7-*b*). Of course, the element is now longer than a half-wavelength. That means that part of the current

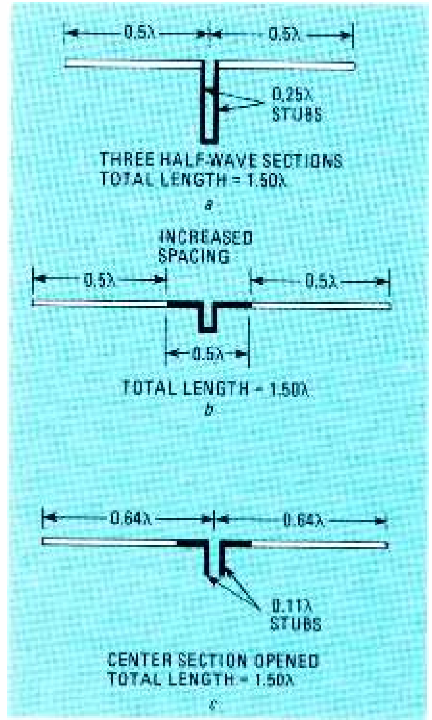


FIG. 7–THE EVOLUTION of the extended double-Zeppelin antenna. In each case, the total length is equal to 1.5 λ.

is out of phase, which reduces the total current and gain. When the spacing between the ends of each element is 0.28 of a wavelength, the increased gain, due to wider spacing, more than makes up for the lower gain caused by the short, out-of-phase sections. So the gain of the antenna is at maximum.

Figure 7-*c* shows the extended double-Zepp with an opening in the center conductor, which is the low-impedance point. However, its impedance is still several times greater than the desirable 50 ohms. A closer match may be obtained by using a standard television transformer-balun, the type used to connect 75-ohm coaxial cable to either a 300-ohm antenna or 300-ohm television input.

The vertical, center-fed Zepp is made of tubing, which allows the feedline to be run down its center where it cannot affect antenna performance. The tubing's diameter must be large enough to handle the coaxial cable, and the bolts that will hold it to the mast.

The antenna is made of ¾-inch tubing, as shown in Fig. 8, which allows the feedline to be run down the center where it cannot affect the antenna's performance.

The center (phasing) stub is made from brass brazing rods; ³⁄₁₆-inch diameter for a VHF-low, and ¹⁄₁₆ inch for the VHF-high or UHF bands. Calculate the length of each section using Fig. 9 as a guide. Then correct the length for the diameter of the material used in each section according to Table 3. The calculation for the stub length must include the length of the leads

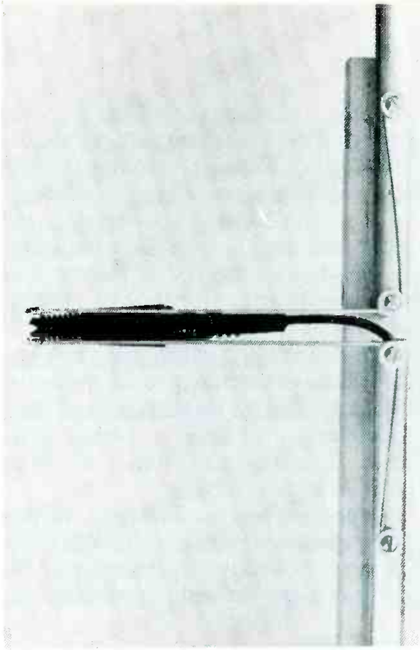


FIG. 8—CENTER OF THE extended double-Zepp antenna. Note the orientation of the balun transformer and phase reversal stub.

on the transformer, see Fig. 10, which should be cut as short as possible.

If the antenna is intended for the VHF-low band, 30–50 MHz, each element will be from 12- to 20-feet long. That means that you'll need more than one length of tubing. Use two sizes, maybe ¾ and ⅞-inch diameters, so that one fits inside the other. Use the larger size for the portions nearest the feedline connection. Cut two one-inch long slots lengthwise on the outside end of larger tube, and insert the smaller one. Use a hose clamp to hold them together.

Drill two $^3/_{32}$-inch holes in each element to mount the antenna on the mast and hold the phasing stub: one ¼-inch from the end and the other about 4–6 inches from the end. Bend the brazing rod to form the stub. That's easily done by temporarily inserting the bolts into the tubing and then bending the rods around them. Cut to the final length after forming the bends.

Mount the antenna and phasing stub near the top of the mast (see Fig. 8) with No. 10 machine screws and washers. Run the coaxial feedline, preferably RG-8/M, through the lower tubing before inserting the screws. The RG-58/U has higher losses, but will fit easily. (If you've chosen RG-8/U, either solid or foamed dielectric, there's will not be enough space for the machine screws and the larger cable.) Secure the tubing to the mast with U-bolts.

Although not necessary, the phasing stub may be bent into a semicircle around the mast. That streamlines the appearance and reduces the stress slightly because the stub does not have to support as much feedline. That's particularly advantageous for the VHF low-band antenna. Solder the transformer leads to the end of the phasing stub, and connect it to the coaxial cable with the appropriate connector.

The mast material must be a non-conductor. Wood that has been weather-proofed with two coats of varnish or polyurethane is a good choice. Shorter antennas for UHF or VHF-high band are easily supported on 2 × 2-inch lumber, but for VHF low, use a 2 × 4 or even a 4 × 4, depending on the height the mast will be. Before raising the mast, cover all the electrical connections with silicone rubber cement to prevent oxidation.

The upper element of the extended double-Zepp does not have to be made of tubing since there's no coaxial cable to shield. For UHF and VHF high band, you may prefer to use brazing rods, very small diameter tubing, or even heavy-gauge copper wire for smaller sections. The lower element is, of course, all tubing. The very top of the upper element is an 8½-foot fiberglass, CB whip antenna.

The whip antenna is bolted to a metal cap, which is then bolted to a lower 5½-foot aluminum tubing. That reduces both wind resistance and weight for this tall, effective antenna. The total length of the antenna will be about 14 feet.

Coaxial-collinear antenna

This antenna is a modification of the stacked-dipole. It is made of coaxial cable and all the elements lie on the same line, hence the name, *coaxial-collinear*. (Refer to Fig. 11.) One side of the dipole is the center conductor of the coaxial cable and

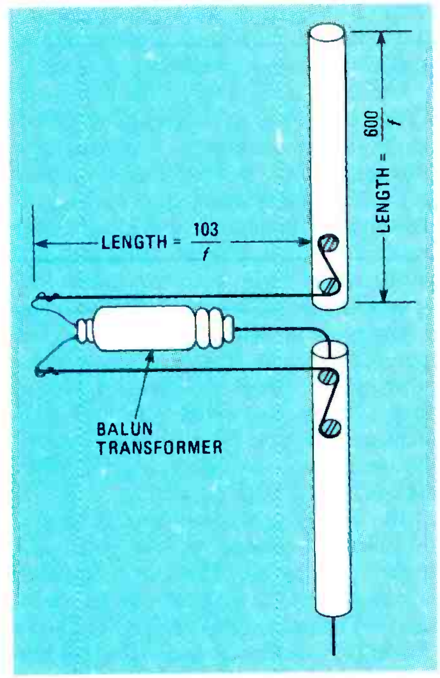


FIG. 9—EXTENDED DOUBLE-ZEPP. Calculate the length of the elements as shown.

the other side is the outside braiding as shown in Fig. 11-*a*. The feedline is connected to the center of a half-wave dipole. Figure 11-*b* shows the dipole folded on itself and Fig. 11-*c* is the folded dipole with the center conductor extended.

Additional half-wave sections are stacked on with the center conductor of each section connected to the outside

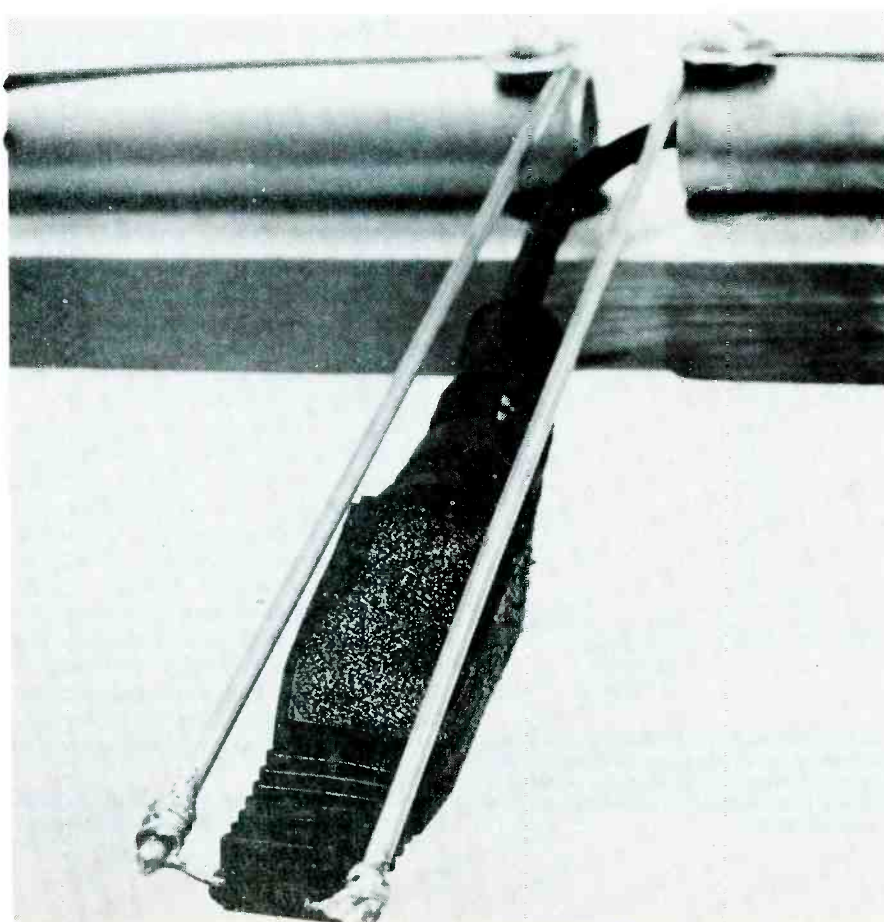


FIG. 10—EXTENDED DOUBLE-ZEPP with balun transformer connected; the transformer leads should be cut as short as possible.

braid of the next as shown in Fig. 11-*d*. The braid acts as a shield, preventing a signal from reaching the center conductor.

The result is that every other half-wave section is exposed to the incoming signal and the induced current is in phase, thus providing gain. The configuration at the top of the antenna array makes each leg of the series of dipoles equal in length. The feedline is therefore connected at the very center, where the impedance is lowest and comes closest to matching the feedline.

The basic design can be modified for more or less gain. Eight half-wave sections provide about a 6-dB gain over a simple dipole, and sixteen sections give about a 9-dB gain. Because of its length, the design is most applicable for VHF high-band and UHF signals.

The coaxial cable used should have a 50-ohm impedance with a solid dielectric. (RF travels slower in solid polyethylene, thus the antenna can be made shorter.) Use either RG-8/U or RG-58/U. The RG-8/U is heavier and stiffer, but has lower losses. The RG-58/U is easier to solder with a small soldering iron.

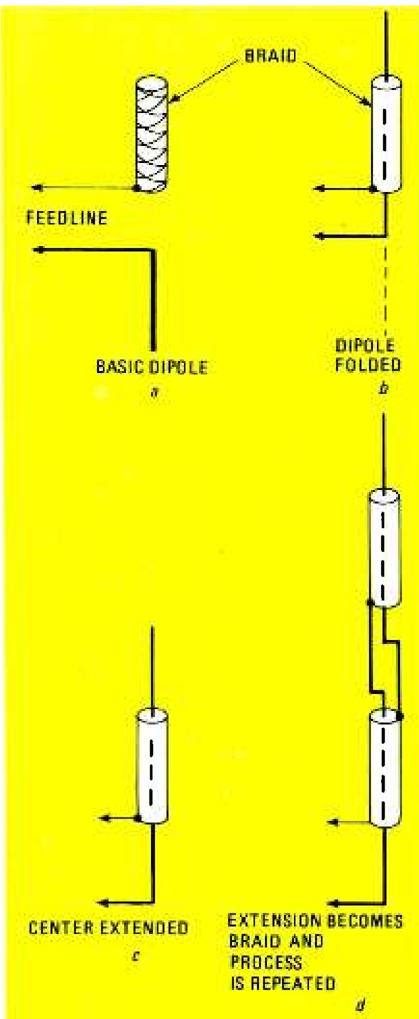


FIG. 11–COAXIAL-COLLINEAR antenna made from coaxial cable: *a* is a basic dipole; *b* shows the dipole folded on itself; in *c*, the center conductor is extended, and *d* shows two stacked coaxial sections.

The single most important requirement for a good coaxial-collinear antenna is patience. The work is not difficult, but it can be time consuming, especially if you're not comfortable with coaxial cable. Concentrate on only one joint at a time. Be careful when connecting the sections; an accidental short circuit can turn your carefully engineered antenna into just a random length of wire.

Calculate the lengths of the sections according to Fig. 12. Then correct for the velocity factor of the coaxial cable you're using, usually 0.66 for the solid dielectric. For example, a half-wave section designed for 155 MHz:

$\lambda = 984/115 = 6.348$ feet
$\lambda/2 = 6.348/2 = 3.174$ feet
$3.174 \times 0.66 = 2.094$ feet

After determining the dimensions, begin by preparing one end of your coaxial cable as shown in Fig. 13. Do *not* cut to length until after the end is properly prepared. That way, if you make a mistake you lose only an inch or so rather than the entire section. Do the same for each of the eight sections, preparing one end and then cutting to length. (By the time you return to complete the other end of each section you'll be an expert!)

Prepare the coaxial cable by stripping away some of the insulation according to Fig. 13; a tubing cutter or knife work well, but be careful if you use a knife. It is a good idea to tin the copper braid before joining the sections, but be careful not to overheat the polyethylene core. If the core melts, it runs over the braid making further soldering almost impossible.

If you use high-quality coaxial cable with a closed braid, you will not experience the difficulty of molten plastic oozing through the spaces, as you would with the cheaper stuff.

After preparing the individual sections, begin connecting them (see Fig. 14). Note that at the joint, the center conductor of each section is joined with the shielding of the next. Be careful that you leave no frayed ends of braid that might short the joint. The best way to handle that is to lay the center conductor of one section on the braid of the next and wrap the braid end around the joint as shown in Fig. 14.

Seal each joint with silicon rubber cement and wrap it securely with electrical tape to protect it from moisture and make it stronger. Slide the completed antenna into a length of heavy-walled (Schedule 40) PVC plastic tubing about ¾ inch in diameter. The thicker RG-8/U coaxial will easily slide through the tubing. But the lighter RG-58/U needs some help: For support, use a small nylon cord about ⅛ inch in diameter cut a foot longer than the antenna. Tie knots in the cord every foot or so and tape to your antenna, starting at the bottom.

Put the tape on the top side of the knot to prevent it from slipping when the entire assembly is in position. Slide the cord through the PVC tubing and pull the assembly through using the cord for support. With the antenna inside the tubing, there will be about a foot of nylon cord protruding from the top. Tie a large knot an inch beyond the end of the top wire section and then cap the end of the tubing, with the knot just outside.

If the cap fits too tightly, file a notch on the outside of the tubing to accommodate the cord. Glue the cap in place and dab a little glue on the knot so it won't come loose. Your antenna is now ready to be taken to its final location.

Depending on the antenna's length, you may want to brace it with lumber. And if it is exceptionally long, you may have to use guy wires as well. Non-stretching polypropylene clothesline is fine. The guy wires don't have to go to the very top because at least 5 feet will be self-supporting even in extremely high wind.

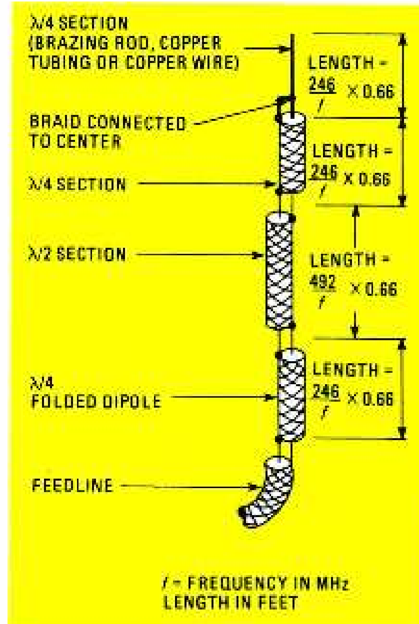


FIG. 12–COAXIAL-COLLINEAR antenna dimensions are shown here. Note that the center conductor of each λ/4 section is connected to the braid of the next.

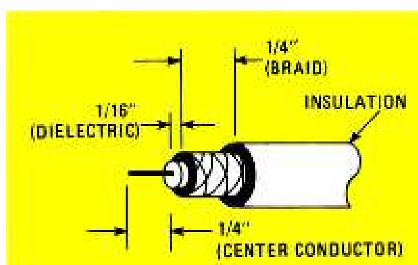


FIG. 13–PREPARE THE COAXIAL cable sections by stripping off some insulation and peeling back the braided sheilding.

Which antenna is best?

The three different antennas described varying in size, complexity, performance, and appearance. Begin designing your antenna by choosing the type that best suits your needs. In making your decision, you must consider all the variables. You can be assured that any choice made is an improvement over your monitor's built-in antenna system.

First, pick the band for which the antenna will be used. If you are lucky, all frequencies used by your local services will be in one band, and close together in frequency. Use Table 1 to help make that selection.

Often you will be interested in frequencies in all three bands; therefore you must decide which is most important to you. That choice should not be too painful. Your new antenna will probably outperform the built-in one on all frequencies solely because it is mounted higher and away from interfering objects.

TABLE 4
ANTENNA SELECTION GUIDE

Band	Ground Plane	Extended Double-Zepp	Coaxial-Collinear
VHF-low	Shortest antenna Radials may need support Good Choice	Fairly tall but no radials	Excessive length
VHF-high	Short Easy construction	Reasonable length Neat installation	Highest gain Neat installation Good choice
UHF	Tiny Easy construction	Small size is difficult to build	Highest gain Neat installation Good choice

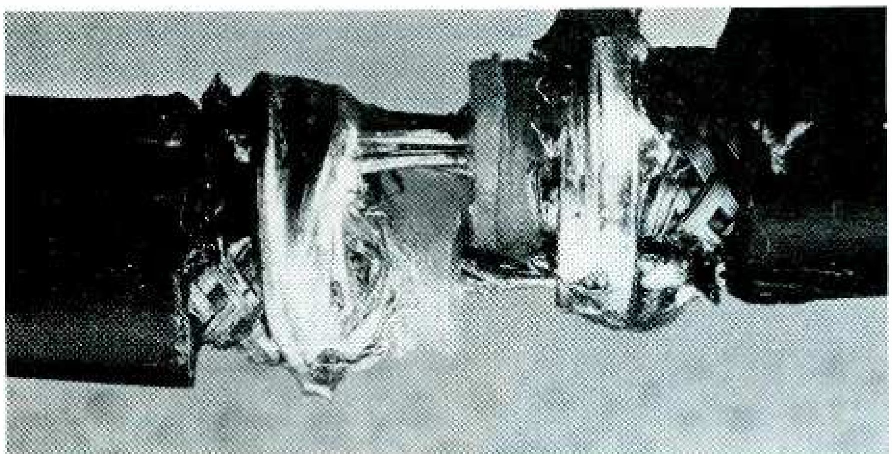


FIG. 14–FINISHED JOINT: Note that the center conductor is placed on the braid and braid ends wrapped around to secure conductor in place before soldering.

After choosing the band, consider how the antenna will look, where it will be located, and is there enough room for the radials; will the coaxial-collinear be too tall? Do you really need a lot of gain? Table 4 is provided to help with that decision. With that out of the way, go to the section that describes the antenna and begin building it. Be sure to follow all instructions carefully.

Installation

For optimum performance, an antenna should be positioned high and in the open. Remember that reception is best when the antenna is within the line of sight of the transmitting antenna. Don't pick a location that is hazardous to get to, and *never* place an antenna near any electrical line before, during, or after installation. And do not mount near metal objects.

Other than the obvious shock hazards presented by power and telephone lines, nearby metal objects can change the effective inductance of the antenna and, thereby, reduce its performance. Also, before installation, ask yourself: "If the antenna falls or is blown down during a storm, where will it land?" It might also be a good idea to ask: "If I fall during installation, where will I land?"

Try to pick a location where you'll need only the minimum amount of feedline. In other words, don't place the antenna 200 feet away from the receiver's location simply to gain 10 feet in height. The height advantage will be overshadowed by additional losses due to the extra feedline. Also try to keep as much of the feedline vertical as possible.

Use coaxial cable to connect the antenna to your monitor. It is rugged, flexible, and the shielding allows you to place it in any convenient location. Running the cable along metal gutters will have no effect. Coaxial cable is available in a wide variety of sizes and efficiencies, with corresponding costs. Pick one that has a nominal 50-ohm impedance.

An important difference between cables is the structure of the dielectric material. If it's foamed it will have significantly less loss at radio frequencies than the solid core. RG-58/U, about ¼ inch in diameter, with a foamed-dielectric is an excellent cable for our purposes. Try to avoid RG-8/U. It is larger in diameter, less flexible, and costs more.

If you can find RG-8/M (miniature RG-8/U) it is also a good choice. It's only slightly thicker than RG-58/U and exhibits a good balance of flexibility and low loss at a reasonable cost. Remember when choosing your cable that signal loss increases with frequency and feedline length. For long runs at high frequencies, it is an excellent idea to use the best cable that you can afford. You'll also need a Motorola-type plug to connect the feedline to your scanner.

The simplest place to bring the feedline into the house is usually in the vicinity of a window. Drill a small hole through a non-movable part that can be easily patched later if necessary. The window frame, top or bottom is best for that. Some houses allow easy access through a basement vent and then up through the floor.

When running coaxial cable, avoid sharp bends and be certain that the external connections are weather sealed. The foamed-dielectric cable in particular can absorb moisture, which increases feedline losses. And don't feel obligated to keep the antenna in the original location chosen. Sometimes raising or lowering it a few feet, or moving it sideways can make a big difference.

There are often unpredictable influences in the area, like power, telephone, or cable TV lines and maybe even your own rain gutters. Regardless of how good your antenna is, there will always be distant, weaker signals barely audible over the noise. The position of the antenna may make a big difference.

Consider turning the disadvantage of a closely placed metal downspout or TV-antenna mast to an advantage. If either is spaced $\lambda/4$ from your antenna and parallel to it, it can function as a reflector. That provides less gain in the direction of the reflector, but more gain in the opposite direction. If you live on the far side of town, that may be exactly what you need.

R-E

HOW IT WORKS

Cellular Mobile Telephones

MARC STERN

Thanks to cellular telephone, the capacity of our mobile telephone systems has increased dramatically. Here's a look at the technology that makes cellular telephone possible.

IMAGINE SITTING ON A BEACH, FAR AWAY FROM HOME OR telephone lines, and being able to carry on a phone conversation with a friend across town, or across the country. Well, the technology necessary to let that minor miracle occur is currently being put in place. What we are talking about is, of course, cellular telephone. With cellular telephone, it is possible to place or receive a call via a mobile or portable unit from almost any location.

Interestingly, the history of cellular communications began in 1968. At that time, the FCC freed the spectrum in the 806-960-MHz region and challenged the communications industry to use that spectrum for maximum public benefit. In 1971, AT&T proposed using those frequencies for a cellular telephone system. In the ensuing years, the technical problems were solved, test systems were built, and rules for the

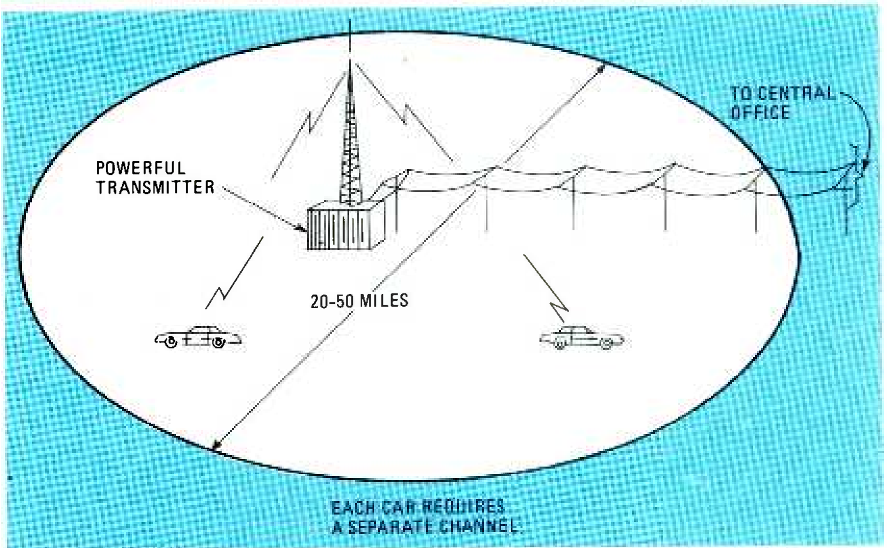


FIG. 1—CONVENTIONAL MOBILE TELEPHONE SERVICE uses one central base station to transmit a powerful signal over an area of up to 50 miles in diameter. Only one two-way conversation at a time can be held over a given channel in the coverage area and the number of channels is limited.

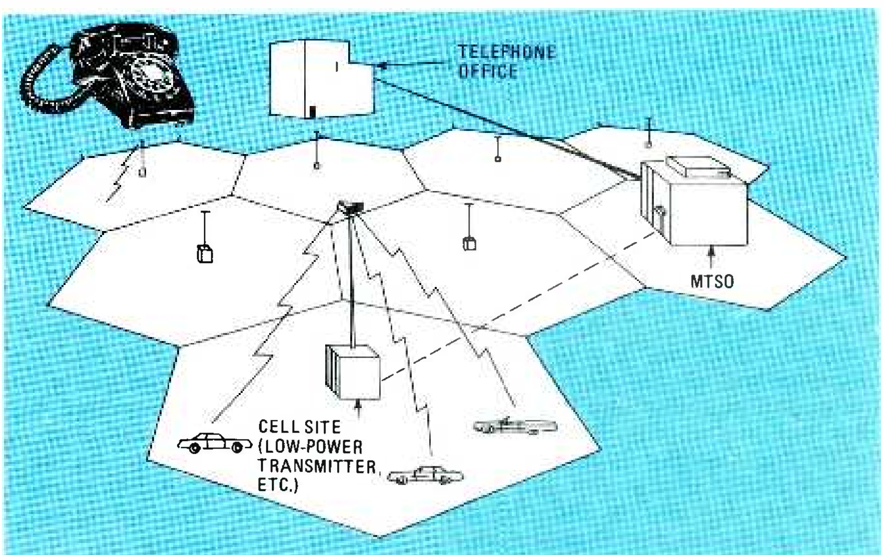


FIG. 2—CELLULAR MOBILE TELEPHONE SERVICE is provided through a system that is composed of three major elements: cell sites, a mobile telephone switching office (MTSO), and dedicated interconnecting circuits. In the cellular system, the coverage area is divided into small areas called cells, hence the name.

cellular industry were issued. In 1983, the first commercial cellular system started operation.

The cellular telephone system

To understand how cellular telephone works, it is necessary to discard some long-held ideas about mobile telephone. In conventional mobile telephone systems, a single central base-station is used to transmit a powerful signal over an area of up to 50 miles (see Fig. 1). In that system, only a single conversation may be held over a given frequency or channel in the service area.

In cellular systems, several low-power transmitters, with their associated receivers, are scattered about an area. Each transmitter operates at a power level sufficient only to cover a small area, called a cell (hence the name). If cells are sufficiently far apart, they can simultaneously use the same set of frequencies. (To ensure proper separation, adjacent cells are assigned different sets of frequencies.) Thus, where only one conversation could occur at a time over a given frequency in a service area, now hundreds could take place over the same coverage area.

Also, instead of using fairly high-powered mobile units—25 watts or more—to carry on conversations, each cellular mobile unit is lower powered ranging from 0.6 to 3 watts. In addition, the cellular system makes handheld portable phones both practical and possible.

Finally, the last notion that must be discarded about traditional mobile-phone systems is a low number of users. In traditional VHF-based radiotelephone systems, due to the low number of conversations that are possible at a time, the saturation level for the system is about 1,200 mobile units. That means that there are few people who can actually use the mobile phone system, and there is usually a long waiting list in any urban area. With cellular telephone, though, as many as 100,000 can make use of the system.

A Cell Is Born

Central to the cellular radiotelephone system is the concept of a cell. That is the service area of one transmitter/receiver and it is just one part of a larger network. As shown in Fig. 2, at the center of the cell is the *cell site*, which consists of a low-power transmitter, a receiver, and an electronic switching center that links the cell to the rest of the cellular system. Each of those cell sites, in turn, is linked to a *M*obile *T*elephone *S*witching *O*ffice (MTSO), which is the ultimate arbiter of the entire cellular network. The MTSO, in turn, links the cellular system with the wire telephone system run by the local phone company.

The electronics that makes the cellular system possible is located at the cell site. In addition to the transceiver (transmitter-receiver) needed for the cellular system, at each site is a sophisticated computer system that not only controls the transceiver, but also the mobile units—in conjunction with the mobile unit's internal microprocessor and circuitry—as well as the local switching operation to the MTSO.

For the cellular system to work, when a car moves from cell to cell, there must be an orderly transition; communications must be transferred cleanly from cell to cell, and the mobile unit must only communicate via one cell site at a time. To achieve that aim, each cell site is assigned a set-up channel, which only handles data signals, in addition to a given number of voice channels. The set-up channel, which is used by all of the mobile units in the cell, is used to initiate calls and assign a user to a voice channel. The receiver in a subscriber's mobile unit scans all of the set-up channels in a system and selects the one that is the strongest. Communications then commence via that cell site and only that cell site.

Transitions between cell sites (see Fig. 3) are handled by the cell site electronics. The mobile unit monitors the voice channel for a "hand-off" signal. That signal is sent by the cell site when the signal strength at the cell site drops below a certain level and it has been determined that another cell site is receiving a stronger signal (each cell site has a scanning receiver for that purpose). The hand-off signal instructs the mobile unit to change frequencies. During the change, the audio

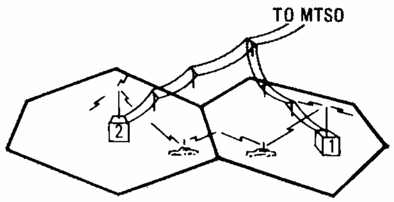


FIG. 3—CELLULAR HAND-OFF occurs as a car moves from cell to cell. During the transfer, which is coordinated by equipment in the MTSO, the user sees no apparent change in transmission quality.

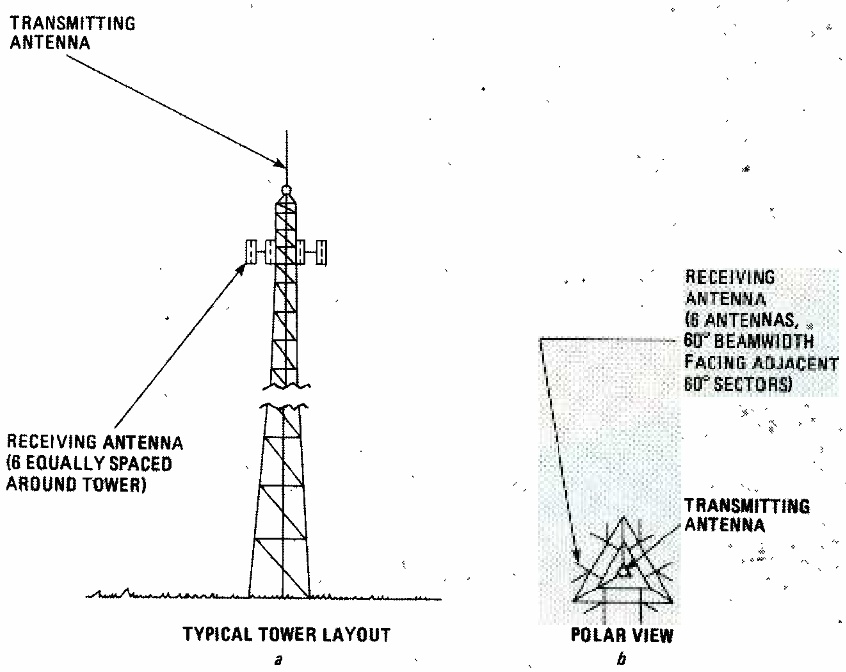


FIG. 4—A TYPICAL TOWER LAYOUT is shown in *a*. Note that the transmitting and receiving antennas are located at different parts of the tower. The arrangement of the receiving antennas, as seen from the top of the tower, is shown in *b*.

is muted for 150 to 400 milliseconds; such a time interval is not perceptible to the user. Once the mobile unit exchanges handshaking signals with the new cell site, communications resume on the new frequencies.

A closer look

Let's look more closely at the cellular radiotelephone system to see how all the electronics and computers do their tasks. And what better way to look at the system than walking through a typical call?

To initiate a call, all a mobile user has to do is lift the handset of his radiotelephone and dial the number he wants. At that time, the microprocessor-controlled unit sends a brief burst of digital information to the transceiver, alerting the cell site that the user wants to make a call and that it is present in the site's coverage area.

Next, the cell site equipment sends a digital signal back to the mobile unit telling it to standby while it is assigned a frequency pair from the frequency allotment assigned to the central site. (Cellular phones operate in the full-duplex mode, which means that both the caller and person called can hear and talk at the same time. To do that, discrete frequencies are used for transmission and reception. The typical frequency separation between transmit and receive is 45 MHz. Spacing between channels is 30 kHz and there are 666 duplex channels in all.)

Continuous contact

One of the interesting capabilities of the cellular radiotelephone system is its ability to provide continuous coverage across a large geographic expanse.

In order to do that as a mobile station moves from one area to another, the entire cellular system must know the exact location of that mobile system and it must be ready to enable a hand-off of that mobile between cell sites—all without the user being aware of it.

To do that requires some interesting computerized gyrations. Look at a cell site tower, such as the one used in the Motorola system and shown in Fig. 4, and you will see something interesting—the transmit and receive antennas are located on different parts of the tower. In a typical installation, such as the ones used in Motorola systems, there are six 60-degree directional receiving antennas spaced around the tower, each with a gain of about 17 dB (see Fig 4-*b*). Diversity reception techniques are used. In diversity reception, signal strengths at the antennas are monitored, with the one receiving the strongest signal being used for the communications. Computers handle the task of analyzing the signal strengths and making the antenna selection.

The receiving antennas and computer equipment also team up to handle another task—determining the position of each communicating mobile unit in the cell. To do that, the computer samples the received signal strength at each antenna, and uses a special direction-finding algorithm to determine the exact location of the mobile unit.

Monitoring continuously, that information is constantly updated and is fed back to the master computer at the MTSO. The computer at the MTSO is the arbiter that takes the information on the location of the mobile unit and if the signal strength falls below a certain level—about 17 dB (carrier-to-interference-and-noise)—the MTSO decides its time for a hand-off between cells.

While all of that is going on, the computer in the MTSO is also polling nearby cell sites, asking them which one is receiving the mobile unit the strongest. The cell sites, in turn, look for the signal and reply. Using the information received from the cell sites, the MTSO orders the call to be switched to the most appropriate cell. At the same time, the mobile unit switches frequencies to a pair that is available in the new cell site. The frequency pair in the old cell site is then freed.

Monitoring the received signal strength is not only important in determining the location of the mobile unit, but it is also important in keeping the power levels within the cellular system down. Signal strength is monitored by the cell site, and when it exceeds a certain level, the cell site orders the mobile unit to cut back on the output power. Thus, the potential for interference is very small.

Cost

At the moment, cellular service isn't inexpensive. Most units are selling in the \$2000–\$3000 range, though prices for equipment will likely drop as more and more units come on the market. As you might expect at that price, most cellular telephones are loaded with bells and whistles. Multi-phone-number memories, last number redial, digital readouts, horn alert (used to alert the user to a call while he is out of the car), and LED status lights used to indicate such things as no service in a particular area are all found on typical cellular phones. As to monthly charges, including access charges and time on the system, those are currently averaging out at about \$150.

Overall, cellular radio is an exciting concept whose time has come. It promises truly portable telecommunications, which will keep anyone in touch wherever they go. **R-E**

BUILD THIS

High-Power FET Audio Amplifier

REINHARD METZ

Get high performance and high fidelity from this FET stereo amplifier. It feels equally at home in your living room or in a disco!

YOU'VE PROBABLY ALWAYS WANTED TO own a high-performance, high-power stereo amplifier. If you don't have one, there are two likely reasons why: You are not sure you need that much power and you are deterred by the cost. But these days, with the increasing popularity of digital audio disc players, there is a new motivation for owning a high-power amplifier that can faithfully reproduce a wide dynamic range without distortion. And while the cost of commercial high-power amplifiers is still high, we'll describe a very high-performance design that you can build at a reasonable cost. Just what do we mean by "high performance?" Table 1 summarizes the characteristics of our design.

One of the most important features of the design is the use of power MOSFET output transistors in a complementary configuration. Those transistors, by themselves, eliminate a number of the problems usually associated with their bipolar counterparts.

The highly desirable characteristics of power MOSFET's for audio amplifiers have been recognized for a few years. However, for many years only N-channel devices were available—only recently have their P-channel counterparts appeared at reasonable prices, making it possible to design amplifiers with remarkable performance but little complexity.

As we'll see shortly, MOSFET's aren't the only transistors used in the amplifier. Ahead of the output stage, a fully complementary bipolar design combines simplicity with high performance.

Why MOSFET's?

Although the evolution of power MOSFET's has primarily been (and still is) fueled by power-supply applications, there are a couple of reasons why MOSFET's make ideal devices for audio-amplifier output stages. First, they allow the design of amplifiers with very wide bandwidths, high slew rates, low distortion, and straightforward simplicity. Also, MOSFET's lack a secondary-breakdown mechanism. (Secondary breakdown in bipolar devices is a localized heating effect in which "hot spots" develop under high-current conditions. A hot spot then conducts even more current, creating more heat, which, in a positive-feedback manner, may lead to a catastrophic destruction of the device.)

Because of secondary breakdown, bipolar devices must be operated within a "safe" area that often falls far short of the device's stated static current and power-dissipation characteristics. Safe-operation-area limiter circuits (whose misoperation has often been notorious) must be used in bipolar circuits. Because MOSFET's do not exhibit secondary breakdown, simpler and more reliable designs can be used.

would make the stage operate far less efficiently.) The relatively high gate-capacitance of the power MOSFET's is also somewhat easier to drive in the common-source configuration.

Resistors R31 through R38 help to suppress the parasitic oscillations that might otherwise occur with the extremely fast transistors used. Zener diodes D14 and D15 limit the amount of drive available to the output. Finally, L1 and R42 serve to isolate the amplifier output from capacitive loads at very high frequencies.

The inverter/driver stage consists of Q15 through Q20. Its purpose is to deliver bias and drive signals to the FET output stage. Their basic requirement is to sit at about 3.5 volts with respect to the source, increasing about .3 volt per ampere of output current. Transistor Q29 forms a conventional voltage multiplier, which, in this case, multiplies the voltage across D3, D4, and D5 and D16 to about 7 volts. The 7-volt bias is presented to the bases of Q16 and Q17, which form the bottom transistors of a pair of complementary cascode amplifiers.

An output-stage gain of 10 is set by R21, R22, R25, and R26. Therefore, the voltage generated by Q29 is split in half and reflected up against the two supply rails as a pair of bias voltages across R23 and R26. Those voltages, along with the AC drive-signals from the previous stage, are passed along to emitter followers Q19 and Q20, which have the high-current drive capacity required by the gate capacitance of the output devices. Using cascode stages here, as well as in the input and voltage-gain sections, serves the dual purpose of splitting the emitter-collector voltage and power drops among two transistors per rail, while increasing the open-loop frequency response of the amplifier.

The voltage-gain stage consists of transistors Q11 through Q14, again configured as complementary cascode amplifiers. The collector loads for Q12 and Q13 are essentially the input impedance of Q16 and Q17. That is in the neighborhood of 50K, leading to a stage gain of about 50 (the quotient of 50K and R17 or R18). Capacitors C3 and C4 increase the frequency response of the stage. Zener diodes D8, D9, D10 and D11 set the base voltages for the upper transistors in the cascodes.

Now we'll look at the input stage, which consists of Q1 through Q8. Those transistors are connected as complementary-cascode differential amplifiers, supplied by current-sources Q9 and Q10. The gain is set at about 100 by the ratios of R3 to R5 and R13 to R11.

Resistor R8 is used to zero the output voltage by varying the collector currents of Q1–Q4, compensating for any V_{BE} offsets that may exist in Q1, Q2, Q5, and Q6. That is important, because with an extremely low output-impedance such as this amplifier has, even very low output offsets (in the tens of millivolts) can deliver many amps into a short.

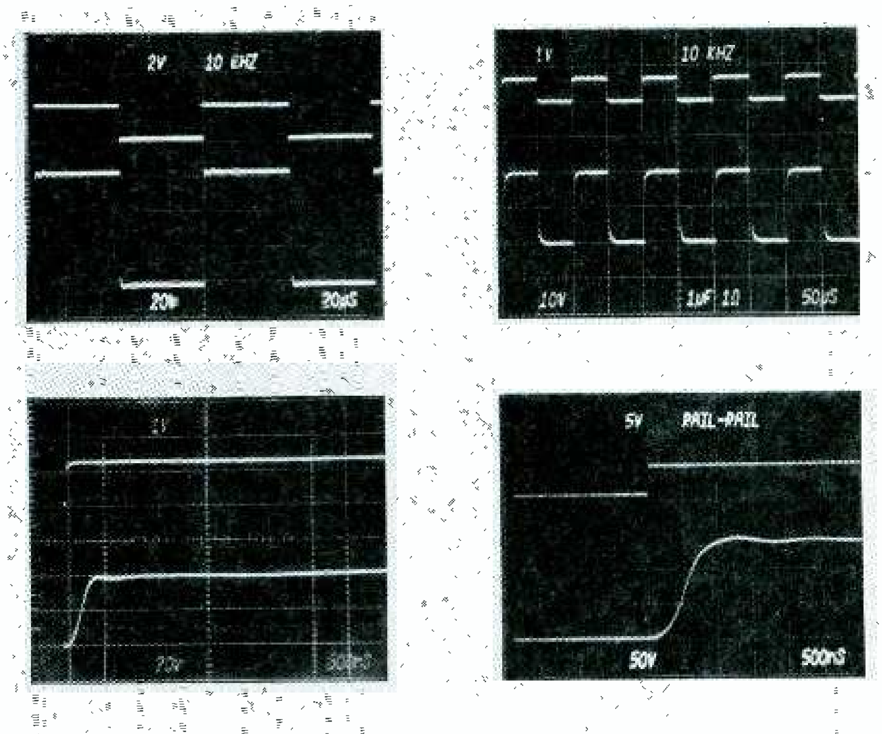


FIG. 3—AMPLIFIER RESPONSE CHARACTERISTICS. *A* shows the response to a 10-kHz squarewave input at 150 watts into an 8-ohm load, while *b* shows the response into a 1-ohm, 1μF load. Shown in *c* and *d* are the step responses at 50 watts and full output, respectively (both with input filter C2 removed). Note the excellent slew-rate and risetime capabilities.

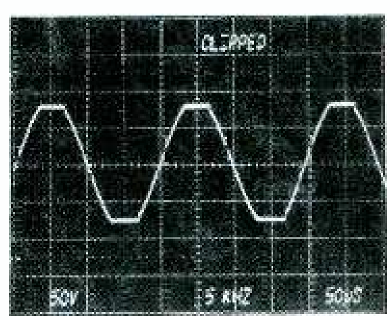


FIG. 4—FULL-POWER OUTPUT with a 5-kHz sinewave input. Note the clipping level is about ±75 volts.

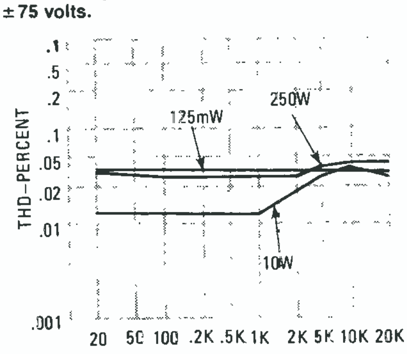


FIG. 5—TOTAL HARMONIC DISTORTION (THD) at 1 kHz.

The overall voltage-gain of the amplifier is set at about 30 by the ratio of R40 to R39. A 3-dB rolloff is set at about 3 Hz by C5. High-frequency compensation is provided by C10, R30, C6, and C11.

Some optional components are shown in the schematic, notably in the power-supply section. First, there is TC1, the thermal cutout made by Elmwood sensors (1655 Elmwood Ave., Cranston, RI 02907). It is normally closed, and opens at 70°C. Another optional component is SR1, an inrush limiter made by Keystone (Thermistor Div., St Marys, PA 15857). For home applications, those shouldn't be necessary. However, if you plan to run the amplifier continuously at high power (in a disco, for example), you should include all the protection you can.

Amplifier performance

Some of the response characteristics of the amplifier are shown in the oscilloscope photographs in Fig. 3. For example, in Fig. 3-a we see the response to a 10-kHz squarewave at 150 watts into 8 ohms. Figure 3-b shows the response with a 1-ohm, 1-μF load. Figures 3-c and 3-d show the step response at 50 watts and full output, respectively. (Those two risetime tests were made with input-filter capacitor C2 removed.) Figure 4 shows the full-power output with a 5-kHz sinewave input. Figure 5 shows the total harmonic distortion from less than 1 watt to 250 watts at 1 kHz.

Building the amplifier

It is essential that a printed-circuit board be used for the amplifier. Figures 6 and 7 show foil patterns for the component and solder side respectively. Note that one board is required for each channel. If you don't want to etch your own boards, etched, pre-drilled, and plated-through boards are available; see the Parts List for information. If you *do* want to etch your own boards from the patterns shown, keep in mind that the board uses plated-through holes. You can, of course, get around that by soldering some of the components, including the output transistors, on both sides of the board. Note that the wiring to the output transistors is incorporated in the PC-board layout. That keeps the wire lengths to the output devices to a minimum. (It also simplifies construction by eliminating 48 wires, reducing the chance of error in that particularly critical area!)

Before we begin with the construction details, we should point out that the values shown in the schematic are for 1%-tolerance resistors. For most applications, it is not essential that you use such parts. Thus, the parts list also shows acceptable values for 5%-tolerance resistors. (One source for 1% resistors is Digi-Key Corporation, Highway 32 South, P.O. Box 667, Thief River Falls, MN 56701.)

Once you have your boards and components, you can begin construction by referring to the parts-placement diagram in Fig. 8 and by installing the fixed resistors. Check the values with an ohmmeter as you go, and be sure that the leads are sufficiently far from the ground plane!

Next, install capacitors, carefully checking values and ensuring that the polarized electrolytic types are properly oriented. Follow by installing the diodes, except for D3–D5. (Those three diodes mount on the output-transistor heat sink, and should not be installed yet.) Again, be careful of the polarity—the diode band indicates the cathode. Next, install the transistors (except for the output transistors Q21–Q28). Transistors Q19 and Q20 should be mounted with insulators and heatsink compound. (If you look closely at Fig. 9, you'll see some heatsink compound around those transistors.) Transistors Q12, Q13, Q15, and Q18 use TO-5-type heat sinks.

Adjust potentiometers R8 and R19 to their middle positions and install. (For R19, which is a multiturn potentiometer, you will need to use an ohmmeter.) You will have to make L1: Wind 15 turns of 16-gauge magnet wire on R42. Solder to the leads of R42, and install the assembly. The PC boards are now complete.

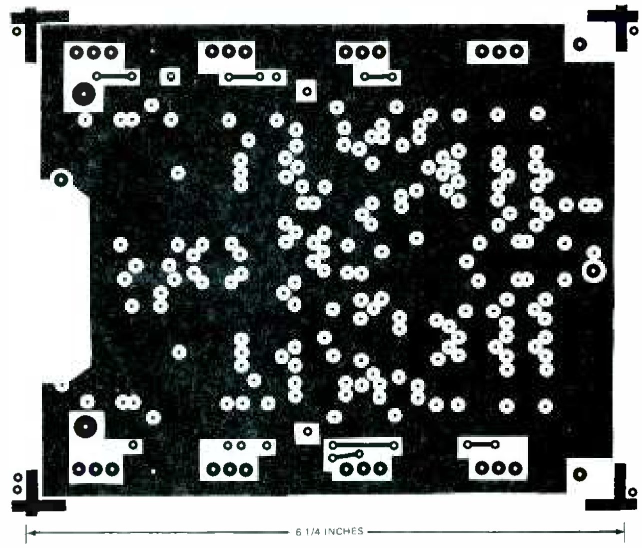


FIG. 6—THE COMPONENT SIDE of the amplifier board is mainly used as a ground plane.

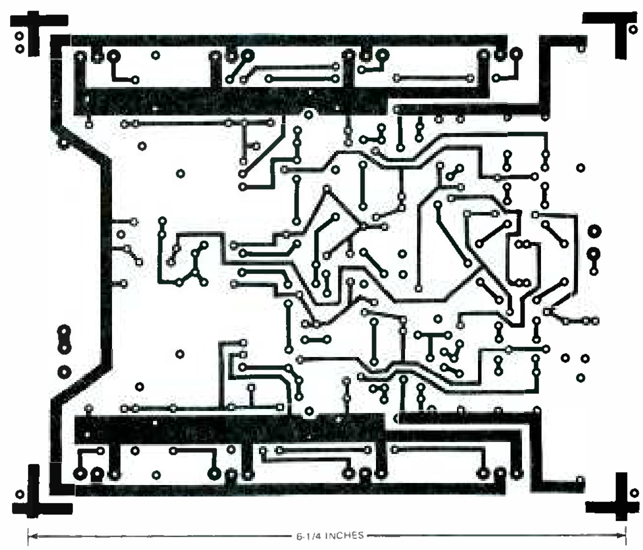


FIG. 7—THE SOLDER SIDE of the amplifier board. Remember that you need one board for each channel.

Preparing the heat sink

The Wakefield heat sinks that are used for the output transistors (see Fig. 10) were not chosen arbitrarily. Their design is almost 100% more efficient for natural convection applications than conventional designs of equivalent volume.

You can use other heat sinks but a minimum surface area of 800 square inches per channel is required. A flat-backed heat sink is desirable for the TO-220 package, but is not essential.

The Wakefield type 512 is available in a 14-inch long extrusion, which needs to be cut in half to yield the two 7-inch pieces called for. After you cut it, drill holes for the output transistors according to the layout shown in Fig. 11. To keep the transistor-mounting hardware to a minimum, you might want to drill and tap the heat sink. However, screws with nuts may also be used. The optional over-temperature sensor and thermal-compensating diodes D3–D5 should also be glued to the heat sink as shown in Fig. 11.

If you have a confined-space application, you can mount the two heat sinks back to back; they will then readily accept a muffin fan for forced convection. For home applications, however, we recommend natural convection—to eliminate the noise, filter, and/or temperature-sensing aspects typically associated with fans.

We should make a final note that wiring length should be kept to a minimum, with less than 2 inches from transistor to PC board. Even with that length, a ferrite bead is necessary on each gate lead, and using coaxial cable is recommended.

Preparing the chassis

The design and construction of a chassis for the amplifier is not critical. The author's prototype was built with rack mounting in mind. It consists of an 8 × 17 inch bottom plate with 1 inch turned up at the front and back. The front plate is 19 × 17 inches. As shown in Fig. 10, the two heat sinks mount on the back of the unit, leaving a 2½ × 7-inch strip for a small plate where the input and output jacks and fuses are mounted. Finally, an 8¼ × 31-inch U-shaped piece of perforated metal makes up the cover.

Begin mounting the components with the transformer, bridge rectifier, filter ca-

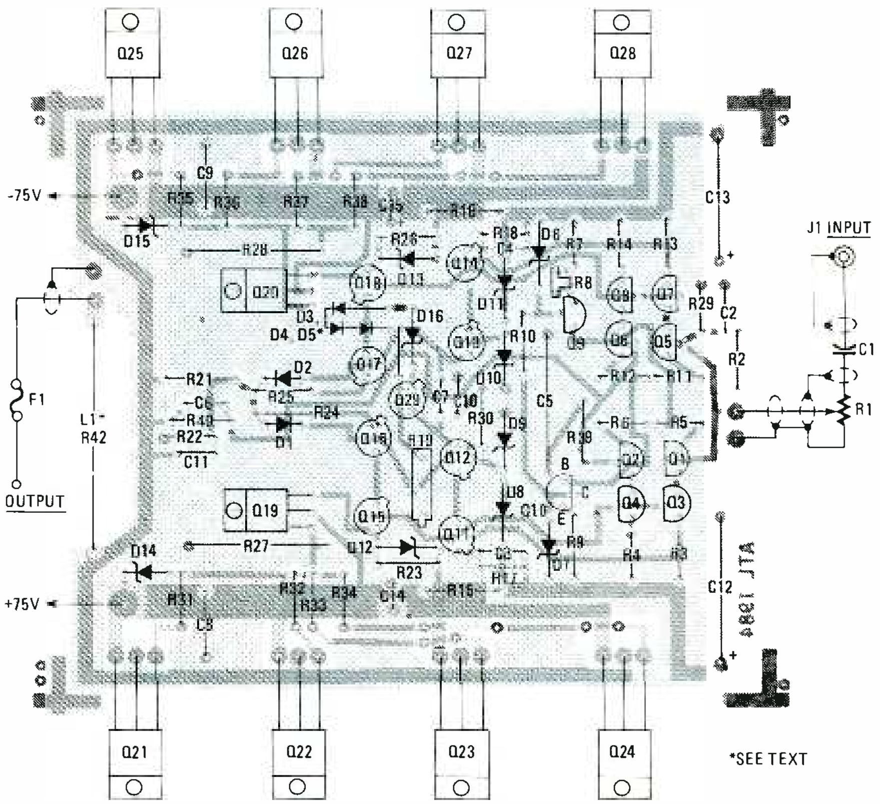


FIG. 8—PARTS-PLACEMENT DIAGRAM for the amplifier board. Refer to the text for information on mounting the output transistors (Q21–Q28) on a heat sink.

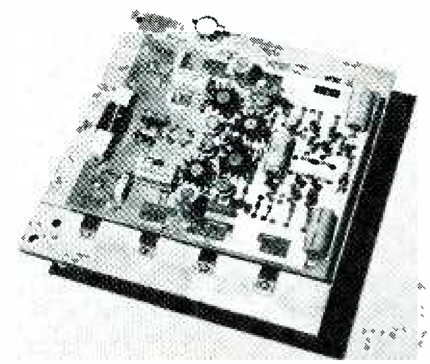


FIG. 9—AMPLIFIER BOARD is shown here mounted on heat sink. Note that Q12, Q13, Q15, and Q18 use TO-5 type heat sinks.

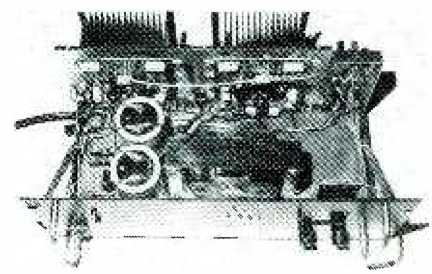


FIG. 10—COMPLETE STEREO AMPLIFIER with cover removed. The chassis configuration is not at all critical.

pacitors, and fuse-holders. Then, mount the power switch, pilot lights, and level controls on the front panel.

Next you'll have to make up a suitable mounting plate and install output jacks that are insulated from their mountings. Install the input-fuse holder and the power cord with a strain relief. Then wire the transformer primary and secondary as shown in the schematic. If you plan to use the optional thermal cutouts, leave a pair of wires to go to the heat-sink area. Use 18-gauge (minimum!) wire in the power supply. We recommend that you use some simple color code for the DC wiring—it will help reduce the possibility of errors during subsequent tests.

Locate a suitable single-point ground, such as a screw through the bottom of the chassis near the power supply, and attach the filter capacitors' common power-supply ground to it. If you use a 3-wire power cord, do not ground or terminate the cord's ground lead.

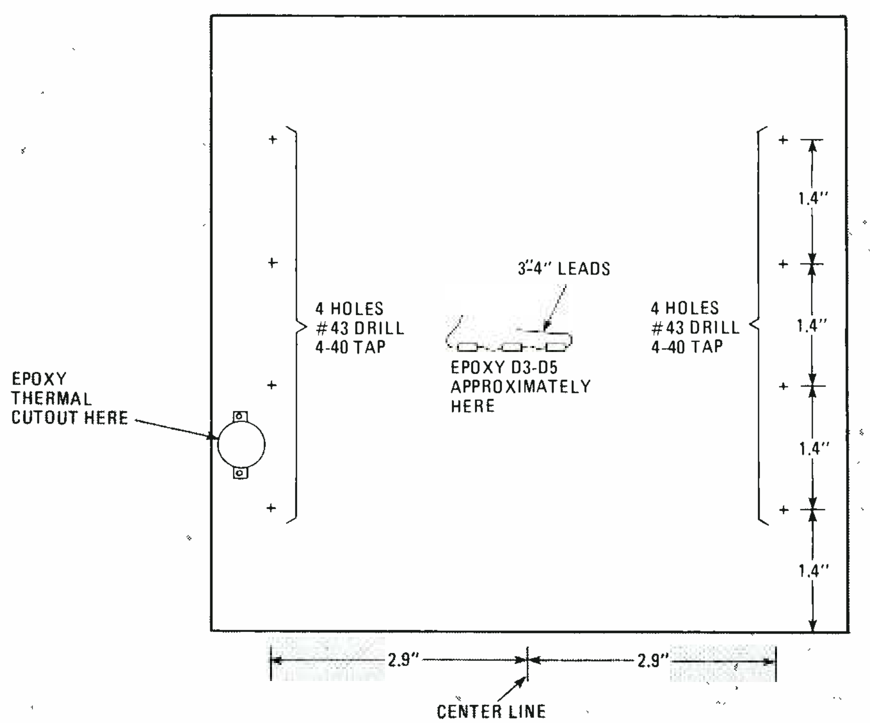


FIG. 11—HEAT-SINK DRILLING GUIDE. Note that some parts are fastened with epoxy to the heat sink.

Checkout procedures

The amplifier checkout is by far the most important part of building this amplifier, so, shift into low gear and **proceed with great care.**

First we strongly advise you to make a final visual check of all parts placements on the circuit boards and the power-supply wiring. Then, before applying any power, measure each supply terminal with an ohmmeter to ground. An initial low reading should slowly move up to high resistance as the capacitors charge. Install the main power fuse and, with the DC fuses F2–F5 not installed, apply power. Check the two supplies for ± 75 volts. Remove power, and discharge the filter capacitors through a 1K resistor.

Next, install a pair of ¼-amp fuses for F2 and F3. Measure the resistance from each power-supply input to ground on both driver boards. The reading should be greater than 100K. If it is, temporarily connect one board to F2, F3 and ground. Connect a clip-lead from the collector of Q4 to the collector of Q3. Connect another clip-lead from the collector of Q7 to the collector of Q8. Temporarily clip-lead D3, D4, and D5 into the current. Apply power, and measure the voltage between

(continued on page 92)

RESISTOR/CAPACITOR

Continued from page 48

dielectric constant between 6.5 and 8.5, can be split into thin sheets, is non-porous, and does not readily absorb moisture.

Mica capacitors are temperature and frequency stable, have a low dissipation factor, and perform well at frequencies up to 500 MHz. Those high precision units are used in a variety of applications, including tuning circuits, oscillators, filters, and RF power circuits.

Glass capacitors

Glass capacitors are used in applications that require high stability in a hostile environment. Those devices can withstand vibration, acceleration, extreme moisture, vacuum, and high operating temperatures; they are, however, susceptible to damage from mild mechanical shocks. They have a life expectancy of 30,000 hours or greater.

Glass capacitors perform very well at high frequencies up to 500 MHz, and have a frequency range of 100 kHz to 1 GHz. Because of their characteristics, those devices are commonly used in missile and spacecraft electronics.

Paper/plastic capacitors

Paper and plastic capacitors are used in applications that require high and stable insulation resistance at high temperatures, and good capacitance over a wide temperature range. (However, an exception to that are the metalized—we'll talk about metalization in a moment—paper units, which have low insulation resistance and are prone to dielectric breakdown.) Plastic types are less affected by humid conditions than paper units since they are non-absorbent. Plastic capacitors, such as polycarbonate and polyester (Mylar) types, are generally intended for applications where minimum capacitance change with temperature is required. They are especially suited for tuned and precision-timing circuits.

In metalized capacitors, a thin film of metal is deposited directly on the paper or plastic dielectric. Doing that gives the capacitor a "self-healing" characteristic

TABLE 2—CAPACITOR SELECTION GUIDELINES

(Continued from page 47)

(AC). Operating temperature from −40°C to +80°C.
Teflon/Kapton: Has a temperature range of −55°C to +250°C with a temperature coefficient of .009%/°C. Teflon's extremely low dielectric absorption makes it good for critical sample and hold circuitry. Those capacitors used in specialized applications such as oil well drilling equipment. Those capacitors are large in size since the dielectric is not available in thin gauges.
Parylene: Manufactured by Union Carbide, those capacitors are equivalent to polystyrene types in performance but are rated to +125°C, versus +85°C for polystyrene.

TANTALUM ELECTROLYTIC
Solid type—
Values: .001 to 1000 μF
Temperature range: −55°C TO +85°C (if derated, to +125°C)
Voltage rating: 6 to 120 volts DC
Tolerance: 5% TO 20%
Leakage current: varies with temperature
Derating factor: 50% voltage
Notes: Used in low-voltage DC applications such as bypass, coupling, and blocking. Not for use in RC timing circuits triggering systems, or phase shift networks due to dielectric absorption characteristics. Also not recommended for applications subject to voltage spikes or surges. High capacitance in a small volume with excellent shelf life. Solid types not temperature sensitive and have lowest capacitance-temperature characteristic of any electrolytic unit. Dielectric absorption and high leakage currents make them unsuitable for timing circuits. Except for non-polarized units, these devices should never be exposed to DC or peak AC voltages in excess of 2% of their rated DC voltage. To prevent failures due to leakage or shorting when series connecting for higher voltages, parallel each unit with a shunt resistor.
Chip types—
Values: .068 to 100 μF
Tolerance: 5% to 20%
Voltage rating: 3 to 50 volts DC
Temperature range: −55°C to +125°C
Leakage current: varies with temperature.
Non-solid types—
Values: .5 to 1200 μF
Tolerance: −15 to +30, and 20%
Voltage rating: to 350 WVDC
Temperature range: −55°C to +85°C (if derated, to +125°C)
Leakage current: varies with temperature
Notes: Polarized foil units are used for bypassing or filtering out low-frequency pulsating DC. Allowance must be made for leakage current. Not suitable for timing or precision circuits due to wide tolerences. Large values available. Etched foil has 10 times the capacitance per unit volume as plain foil types. Peak AC and applied DC voltages should not exceed rated maximums. Usable to 200 kHz. Non-polarized foil are used in tuned low-frequency circuits, phasing low-voltage AC motors, and in servo systems. Sintered slug units are used in low-voltage power supply filtering and in DC applications. Can not withstand any reverse voltage. Leakage current lowest of all tantalum types; no appreciable leakage below 85°C. Usable to frequencies of 1 MHz.

ALUMINUM ELECTROLYTIC
Values: .68 to 220,000 μF
Tolerance: −10 to +75%
Voltage rating: up to 350 volts
Temperature range: −55°C to +85°C (if derated, to +125°C)
Dissipation factor: varies with temperature
Temperature coefficient: varies with temperature
Notes: Used in filter, coupling, and bypass applications where large capacitance values are required and capacitances above nominal can be tolerated. Sum of the applied AC peak and DC voltages should never exceed the the rated DC voltage. Aluminum electrolytics are larger than tantalum electrolytics but less expensive. Loss of capacitance, to as little as 10% of rated value, will occur as the aluminum oxide electrode electrochemically combines with the electrolyte. Oxide film deterioration also requires capacitors to be "re-formed" after storage to prevent dielectric failure. That involves application of rated voltage for a period of 30 minutes, or more, to restore initial leakage current value. Over time, dissipation factor can rise by as much as 50%. Four terminal devices are available (two leads for each connection) that offer low ESR and inductance at high frequencies. Those units were designed for use in switching power supplies.

TRIMMER CAPACITORS
Values: range from .25 to 1 pF and 1 to 120 pF.
Glass/Quartz: Low loss, high Q, and high stability for high tuning sensitivity applications. Frequency range up to 300 MHz.
Sapphire: High level of performance between 1 and 5 GHz.
Plastic: High grade units can be operated up to 2 GHz.
Ceramic: Smallest sized single turn units with maximum capacitance under 100 pF. Capacitance changes with temperature.
Air: High level of performance through UHF Band, from 300 MHz to 1 GHz.
Mica: Has wide capacitance range and relatively high current handling capability.
Vacuum/Gas: Used for high voltage applications. Values from 5 to 3000 pF, with voltage ratings from 2 to 30 kilovolts (DC).

called "clearing." If there is a hole or contaminent in the dielectric of the capacitor, a short may occur, resulting from the heavy current flow in the fault area. In a metalized capacitor, that heavy current flow will melt away a very small part of the thin metal film, thus disconnecting the fault from the capacitor. These capacitors are best for analog circuits because the momentary current flow during the clearing action may result in a spurious signal and cause false triggering in digital logic circuits.

Metalized plastic devices work well in switching power-supply output filters because they have a comparatively low ESR, as well as stable temperature characteristics. When using those capacitors in such an application, however, be sure that the unit selected is rated to handle the voltage surges produced by the circuit.

TABLE 4

Letter Symbol	Low Temp.	Number Symbol	High Temp.	Letter Symbol	Maximum Capacitance Change
Z	+10°C	2	+45°C	A	±1.0%
				B	±1.5%
				C	±2.2%
		4	+65°C	D	±3.3%
Y	−30°C			E	±4.7%
		5	+85°C	P	±10.0%
				R	±15.0%
		6	+105°C	S	±22.0%
X	−55°C			T	±22%–33%
		7	+125°C	U	±22%–56%
				V	±22%–82%

Tantalum electrolytics

Tantalum capacitors offer high capacitance in a small package size and have an excellent shelf life. Various types of tantalum electrolytic capacitors are available including solid, sintered slug, plain foil, etched foil, wet slug, and chip. Applications include low-frequency filtering, bypassing, coupling, and blocking. The solid types are not temperature sensitive and have a lower capacitance-temperature characteristic than any other electrolytic capacitor.

Applications that tantalums are not suitable for are in RC timing circuits, triggering systems, or phase-shift networks. That's because they have high "dielectric absorption" characteristics. That is, when a capacitor is discharged, the dielectric retains a residual charge. Thus, even if a capacitor that has a high dielectric absorption characteristic has been discharged to "zero," it may still be holding a considerable charge. That, as you might imagine, can cause considerable problems in timing circuits and the like.

Tantalum capacitors also are not recommended for circuits that produce spikes, surges, or pulses. If their voltage rating is exceeded by even a few volts, the device is likely to fail.

Tantalums may be polarized or non-polarized. Polarized capacitors should never be exposed to a reverse DC or peak AC voltage greater than 2% of its rated DC voltage. Non-polarized units, as their name would apply, do not suffer from that limitation. Non-polarized units are made up of two polarized units in series with their cathodes connected together.

Aluminum electrolytics

Aluminum electrolytic capacitors are generally larger than tantalums, and are less expensive. One problem with aluminums is that they will change capacitance (drift) over time. That is caused by the aluminum oxide electrodes chemically combining with the electrolyte. Because of that, capacitance can drop substantially, to 10% of rated values. Those units also have a limited shelf life due to oxide film deterioration and must be "re-formed" after long periods of storage. Re-forming consists of applying the capacitor's rated voltage to the unit for a period of 30 minutes. Re-forming also prevents dielectric breakdown or shorting. In addition, the dissipation factor of these devices can rise as much as 50%.

To prevent electrolyte evaporation and component cleaning problems, aluminum electrolytics sometimes have an epoxy end seal. However, without a vent, such capacitors may explode if exposed to reverse or overvoltage conditions.

Aluminum electrolytics are used in filtering, coupling, and bypass applications were large capacitances, and capacitance that are higher than the nominal value, can be tolerated.

Trimmer capacitors

Trimmer capacitors fall into three categories: multi-turn, single turn, and compression types. Multi-turn capacitors have either glass, quartz, sapphire, plastic, or air dielectrics, while single-turn devices use ceramic, plastic, or air dielectrics. Compression types use a mica dielectric.

Glass, quartz, or air dielectric devices are selected for applications requiring low loss, high Q, stability, and tuning sensitivity. Glass and quartz devices are used at frequencies up to 300 MHz. Air dielectrics are usable to about 1 GHz. For frequencies of 1 GHz, sapphire dielectrics offer the best performance.

Ceramic and plastic styles are less expensive, with high grade plastic dielectric devices being usable at frequencies up to 2 GHz. R-E

TABLE 3—GLOSSARY

DC leakage—Small current that flows through or across the surface of the dielectric or insulation of the capacitor.

Dielectric—Insulating material between the plates of a capacitor.

Dielectric absorption—A property of a capacitor's dielectric such that even when the capacitor is discharged to zero, a residual charge remains stored in the dielectric.

Dissipation Factor—Important in AC applications, it is the ratio of effective series resistance (ESR) to capacitive reactance X_C, and is usually expressed as a percentage. The dissipation factor factor varies with temperature, humidity, and frequency.

Electrolyte—Current conducting solution (liquid or solid) between two electrodes or plates of a capacitor.

Equivalent series resistance (ESR)—Energy losses in the capacitor due to lead resistance, termination losses, and dissipation in the dielectric.

Insulation resistance (IR)—Measure of a capacitor's insulation quality expressed either in megohms or as a time constant, RC, in seconds. That value determines a capacitor's leakage current for a continuously applied DC voltage when a capacitor is fully charged.

Temperature coefficient—A capacitor's change in capacitance per °C. May be positive, negative, or zero and is usually expressed in parts per million per °C (PPM/°C).

Working voltage (WVDC)—The recommended maximum voltage at which a capacitor should be operated.

Quality factor (Q)—A figure of merit used mostly in tuned circuit applications. It is defined as a 1/DF or X_C/ESR.

CMOS CLOCKS

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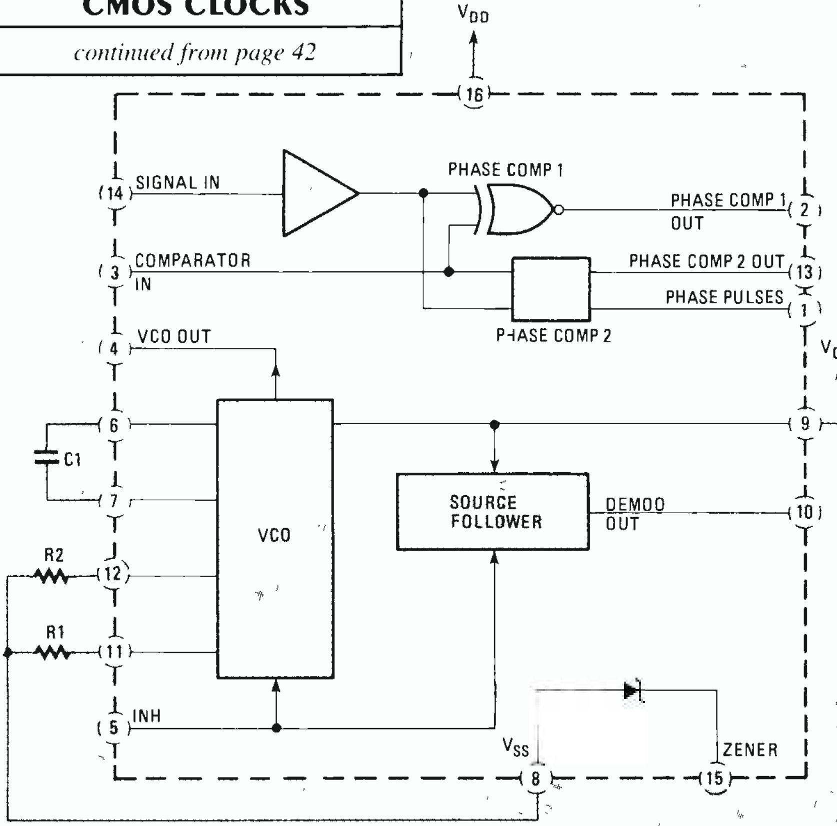

FIG. 17—INTERNAL BLOCK DIAGRAM of the 4046 phase-locked loop IC.

mines the maximum frequency that can be obtained (with the pin 9 voltage at maximum) and R2 controls the actual frequency by applying a control voltage to pin 9:

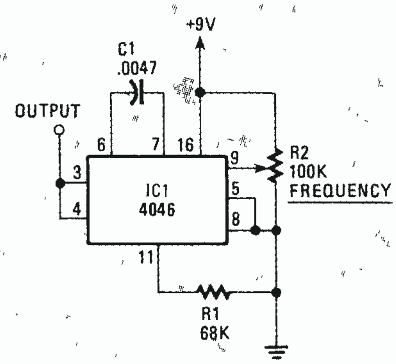

FIG. 18—A BASIC WIDE-RANGE VCO spanning from about zero to about 5 kHz (determined by R2).

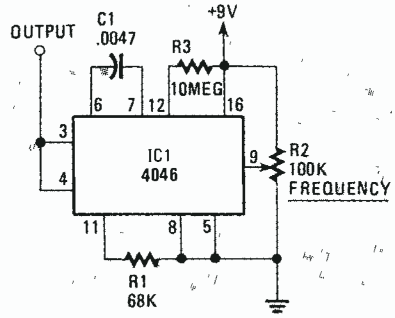

FIG. 19—THE FREQUENCY OF THIS VCO can be varied all the way down to zero.

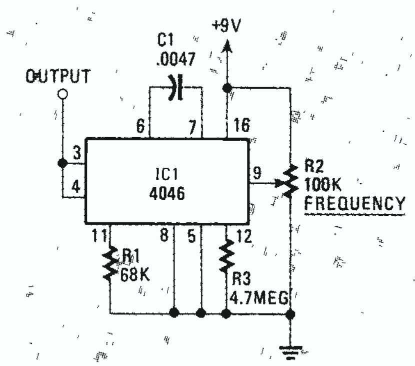

FIG. 20—THIS RESTRICTED-RANGE VCO has a frequency range from about 72 Hz to 5 kHz.

The frequency falls to a very low value (a fraction of a Hz) with pin 9 at zero volts. The effective control-voltage range of pin 9 varies from roughly 1 volt below the supply value to about 1 volt above ground, and gives a frequency span of about 1,000,000:1. Ideally, the supply voltage to the circuit should be regulated.

We've said above that the frequency of the circuit shown in Fig. 18 falls to *near*-zero when the input voltage is reduced to zero. Figure 19 shows how the circuit can be modified so that the frequency falls all the way to zero—all that's needed is a high-value resistor (R3) between pins 12 and 16. Note here that, when the frequency is reduced to zero, the VCO output randomly settles in either a logic 0 or a logic 1 state.

Figure 20 shows how the pin-12 resistor can be used to determine the minimum operating frequency of a restricted-range VCO. In that circuit, f_{MIN} is determined by C1-R2 and f_{MAX} is determined by the combination of C1 and the parallel resistance of R1 and R2.

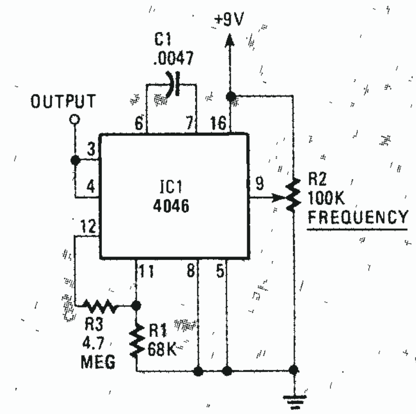

FIG. 21—ANOTHER RESTRICTED-RANGE VCO. The maximum frequency is determined by the C1-R1 time constant; the minumum frequency is determined by the time constant C1(R1 + R3).

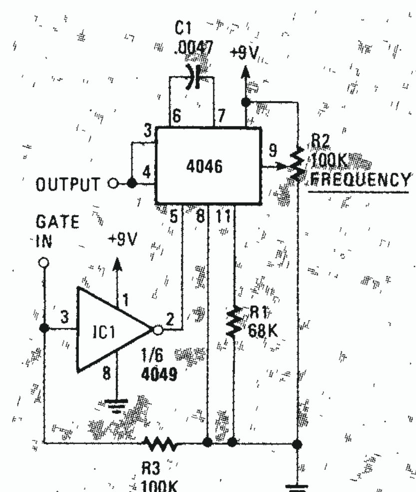

FIG. 22—THIS GATED WIDE-RANGE VCO uses an external inverter.

Figure 21 shows an alternative version of the restricted-range VCO, in which f_{MAX} is controlled by C1-R1 and f_{MIN} is determined by C1 and the series combination of R1 and R2. Note that, by making a suitable choice of the R1 and R2 values, the circuit can be made to "span" any desired frequency range from 1:1 to near-infinity.

Finally, it should be noted that the VCO section of the 4046B can be disabled by taking pin 5 of the package high (to logic 1 level) or enabled by taking pin 5 low. That feature makes it possible to gate the VCO on and off by external signals. Figure 22 illustrates that feature and shows how the basic voltage-controlled oscillator circuit can be gated via a signal applied to an external inverted stage. **R-E**

MOTION DETECTOR

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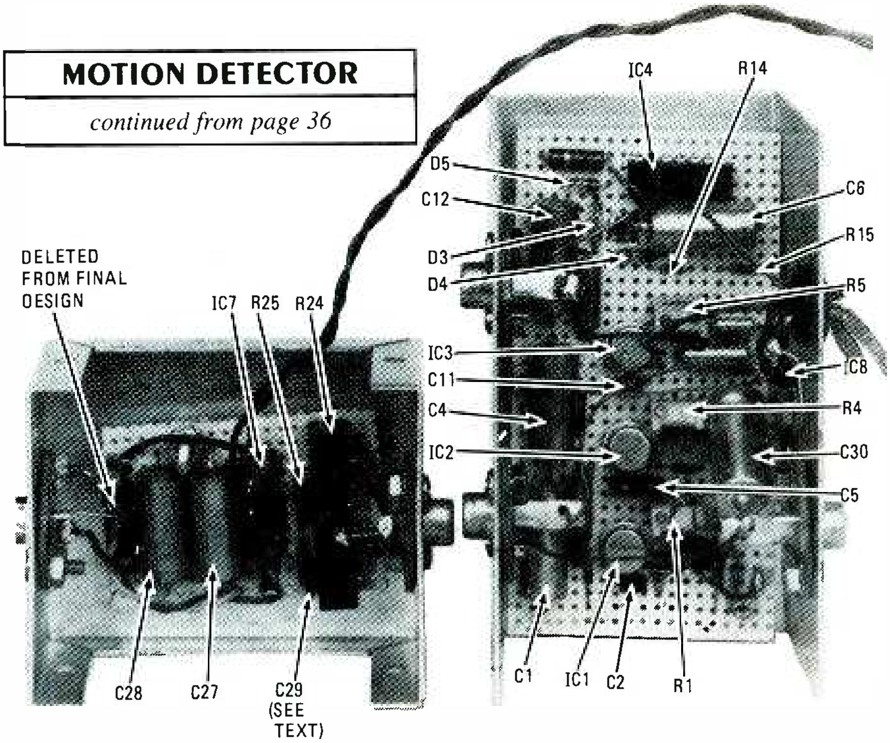

FIG. 6—THE AUTHOR'S PROTOTYPE was built on perforated construction board. Note that the unit shown here, the receiver/output-amplifier combination used in multi-unit systems, is a prototype and differs slightly from the final design.

screws or glue. Be sure to cut holes out of the front piece to allow sound to leave or reach the tweeters unimpeded.

Circuit alignment

The easiest way to align the circuit is with an oscilloscope, although it can also be done with a VOM or VTVM.

Let's first check out the transmitter, referring back to Fig. 3 as we go. Power up the transmitter with the speaker connected. If the circuit is operating, there is a good chance a loud high-pitched tone will be emitted from the tweeter, so you may want to do this part of the checkout in a secluded part of your house! Connect your test instrument to pin 3 of the 555 timer. If using a scope, you should see a 12-volt P-P squarewave. If using a VOM, you should see about 6 volts on the DC scale. Moving on to the output of the LM380, connect to the speaker side of the output coupling capacitor. When using a scope, you should see a fairly distorted sinewave of about 10-volts P-P. If using a VOM, there should be about 3.5 volts on the AC scale. The level control of the line driver and/or output amplifier should be adjusted to obtain the above values. If you have a frequency counter, adjust the frequency potentiometer to get about 17 kHz. If you don't have a counter, a rough adjustment can be made by turning the frequency potentiometer so that a loud high pitched tone is heard. Then adjust the potentiometer so that the tone gets higher in frequency. Continue turning the potentiometer until you can barely hear the tone produced. For the average ear, you should now be adjusted to around 17 or 18 kHz.

Receiver alignment is almost as straightforward as the transmitter. You probably noticed that T1 is not located on the receiver board. To save room on the circuit board, it is mounted on the receiver tweeter. Connecting the receiver tweeter to the receiver board and applying power to the unit, we are ready to proceed. Note: to align the receiver, the transmitter must be operating as it is the signal source. It will help to have both tweeters pointing in the same direction and away from moving objects. Also, try to point them toward a wall or surface that is no less than 10 feet away.

First of all, the DC-level potentiometers, R1, R4, and R5 on all the op-amps, should be adjusted. Disable the transmitter for those measurements since they are DC adjustments. Starting with IC1, a scope or meter should be connected to pin 6 of each respective op-amp. Adjust IC1 and IC2 to read about 5.25-volts DC. Adjust IC3 to get about 6-volts DC.

Now turn on the transmitter. Looking at signal at pin 6 of IC1 with a scope, you should see some indication of a 17-kHz sinewave. You should be able to see some small amount on the AC scale of your VOM or VTVM. Depending on your meter, you may need to put a 1-μF capacitor in series with the meter to block the DC level at the measurement points. If you see no signal at that point, it is time to adjust the transmitter frequency to obtain maximum signal. It will help to point the transmitter tweeter directly toward the receiver tweeter.

Assuming you have a 17-kHz signal at IC1, we can now check out IC2. Connect your scope or meter to pin 6 of IC2. You should see several volts of 17-kHz signal at that pin. Next we'll set the 555 frequency and the transmitter-output level. Point both speakers in the same direction, away from nearby objects. Observing your scope or meter, make sure the signal level is less than 7-volts P-P on the scope or less than 2.5-volts RMS on the AC meter. Adjust the transmitter-level control to obtain those voltages. Now adjust the transmitter-frequency control for maximum indication on your scope or meter. That is the final setting for the frequency potentiometer. Be sure to have the level potentiometer set for about 7- volts P-P at IC2. It is interesting at this point to observe the amplitude modulation of the 17-kHz signal that is caused by movement.

On to the final amplifier stage. Detector diodes D1 and D2 and the following low-frequency bandpass filter feed a signal to IC3 that is proportional to the low-frequency amplitude variations of the 17-kHz carrier. IC3 amplifies that voltage to a useful level. Connect your scope or meter to pin 6 of IC3. With the sensitivity control set to mid-range, you should see about 1-volt P-P or ⅓-volt RMS, which represents circuit noise etc. Moving your hand in front of the speakers should cause the output of this stage to hit both rails. Your scope should see a squarewave down to about 1 volt and up to about 11 volts when a moving object is near the tweeter. An AC voltmeter should see greater than 3 volts with nearby movement.

The last stage of the receiver is a 74LS14 Schmitt trigger, IC4. Its signal comes from diodes D3 and D4, which rectify the low-frequency AC of the previous stage. The output of the diodes is connected to an integrator, which is connected to the input of the 74LS14. If all is well, when the voltage at that point reaches about 1.7 volts, pin 4 of IC4 will go high and LED1 will light, indicating movement in front of the detector.

Interfacing

Interfacing the unit to the outside world is a matter of preference. Using an intruder alarm as an example, the easiest way to do something useful with the circuit would be to connect the output directly to a "noise maker" of some type. You would probably want to have an outside hidden or key switch to turn the unit on or off.

A more sophisticated approach would be to drive a one-shot (possibly made from the unused sections of the 74LS14 and some capacitors) to keep the alarm on for a minute or so to ensure that the intruder leaves! In the author's home, a KIM computer and interface provides power and monitors the outputs of five units. A one-key code on the KIM keypad enables the units when the house is empty, and a six-key code turns off the units when the house is occupied. **R-E**

EQUIPMENT REPORTS

continued from page 10

be "in the ballpark" the recorder works properly. Once the tuning is set for a particular station, it does not have to be readjusted because the recorder can accommodate a rather broad receiver drift. (We got excellent results from a low-cost receiver.) Prior to broadcasting weather charts, the radiofacsimile station transmits an automatic start signal that shifts 1500 Hz and 2300 Hz at a 300 Hz rate for 5 seconds. The recorder starts, prints the chart, and is automatically stopped when the station broadcasts the same tones, but at an alternating rate of 450 Hz for 5 seconds.

Part of the initial setup procedure requires adjusting the framing so the picture is "centered" on the paper, thereby avoiding loss of part of the picture. That is done by observing the print as it is made by the stylus and pressing the FRAME switch until the chart is centered on the paper. The FRAME switch causes the framing to change in small discrete increments, and we found about five to seven increments was all it normally took to center the chart.

Once the chart is framed, the framing procedure does not have to be repeated as long as the same station is received.

The recording rate is 120 spm (Scans Per Minute). It takes approximately 15 minutes to receive a 10- × 12-inch chart. A station might broadcast several charts followed by an "end" tone, which stops the recorder. The cycle will be repeated the next time a chart is broadcast.

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IBM-COMPATIBLE MATRIX PRINTER

Canon has showcased its latest advance in NLQ Printers. The company's new A-40 impact matrix printer provides maximum support for IBM PC application programs. It's printing speed is a fast 140 characters-per-second in draft mode (11 × 9 dot matrix, Pica). In NLQ mode, the simple press of a button produces a sharp 23 × 8 matrix at the speed of 27 characters-per-second.

CIRCLE 226 ON FREE INFORMATION CARD

Its linefeeding speed is 8 lines-per-second, with selectable linefeeding of 1/6, 1/8, and 7/72 of an inch, and programmable. The A-40 is equipped with IBM graphics printer character Set 2, and features escape codes that are fully compatible with IBM's graphics printer.

The machine has quiet operation—less than 60 dB—and will be welcome in any office environment. It can handle fanfold, single sheet and multipart plain paper. Weighing less than 17 pounds, the A-40 can be moved from one office to another with little effort. For further information, write to: Printer Division, Canon USA, One Canon Plaza, Lake Success, NY 11042: Tel: 516/488-6700. **R-E**

FET POWER AMPLIFIER

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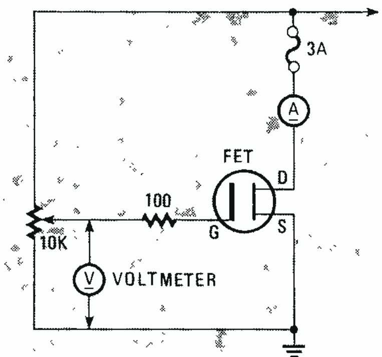

FIG. 12—TO CHECK THE MATCHING OF TRANSISTORS, you might want to use this simple circuit. Start by setting the potentiometer's wiper voltage to zero. Then turn it up to the desired drain current and measure the voltage as shown. For N-channel devices (IRF630), V should be +5 volts. For P-channel devices (IRF9630), V should be −5 volts.

the bases of Q16 and Q17. It should be near 7 volts. Adjust R19, and observe this voltage changing. Leave it at 6.8 volts. Measure the voltage from the emitter of Q19 to the +75-volt supply, and the voltage from the emitter of Q20 to the −75-volt supply. One should be around 7 volts and the other about .6 volt. Remove power, discharge the filter capacitors, remove clip leads, and repeat with the other driver board.

Next, solder the output transistors to the driver board. Note that it is important that the transistors be matched (within each particular type) so that they will share the output current equally. A simple circuit for checking the matching is shown in Fig. 12. They should be matched to be within 100 millivolts of gate voltage at 50 mA of drain current and 200 millivolts of gate voltage at 2 amps of drain current. Make the 2-amp measurement quickly.

To mount the transistors, first bend the leads up at a 90-degree angle right at the point where their width changes. Spread the leads a bit and insert in board. Solder carefully while aligning the transistors as much as possible in a common plane. (They may temporarily be screwed to the heat sink as a holding fixture for this operation.) Solder short leads from D3–D5 to the bottom of the driver board, carefully observing polarity. Apply heat-sink compound and insulators to the transistors, and screw the driver and output-transistor assembly to the heat sink, using insulating shoulder washers. Tighten carefully.

Measure each transistor's tab (or case, if you are using TO-3's) to the heatsink. The readings should all be infinite, indicating no insulator shorts. (If you are using TO-3 output parts, it will be necessary to run individual leads to each transistor. When doing that, be extremely cautious: Double-check all your connections and keep your leads as short as possible. Don't forget to install a ferrite bead on each gate lead if you are using TO-3's. In no case should the wiring to the transistors be more than 2 inches in length.) Install the heatsink and driver assemblies.

Wire one channel to F2 and F3 with 18-gauge (minimum) wire. Connect a wire from the circuit board ground, near the output, to the chassis single-point ground. Install a ½-amp fuse for F3, and a 1-mA fuse for F2. Apply power, and check for a current through F3 of less than 500 mA. Also check that the output voltage at L1 is between ± 1 volt. If either of those tests fail, immediately turn off power, and look for the source of the problem before proceeding. Adjust R19 to set the current through F3 to about 250 mA, corresponding to an output idle current of about 150mA. Next, adjust R8 carefully to bring the output voltage at L1 as close as possible to zero. Turn off the power, and repeat for the second channel, using fuse positions F4 and F5.

Upon completion of those initial tests, finish wiring the remainder of the chassis. Run at least 18-gauge wire from each driver-board output, along with a ground from the board to the output binding posts.

For continuous full-power applications, it will be necessary to use 5-amp fuses for F2–F5, and 8-amp output fuses for F1. However, for normal, or even loud general listening situations, it is advisable to use much smaller fuses to protect the speakers. It is usually sufficient to use 2-amp supply and 1- or 2-amp output fuses, and work up from there if necessary. **R-E**

PARTS LIST—BARGRAPH DISPLAY and CLIPPING INDICATORS

All resistors are ¼ watt, 5%, unless otherwise specified.

R43—24,000 ohms
R44, R46, R53—12,000 ohms
R45, R52, R70—22,000 ohms
R47, R54—1000 ohms
R48, R55—470,000 ohms
R49, R51, R58, R59, R61, R62—10,000 ohms
R50, R56—150 ohms
R57, R60—53,000 ohms
R63, R65—1200 ohms
R64, R66—7500 ohms
R67—350 ohms, 20 watts
R68—15,000 ohms
R69—2200 ohms, 5 watts

Capacitors

C18, C19—1 µF, 10 volts, electrolytic
C20—2.2 µF, 10 volts, electrolytic

Semiconductors

IC1—LM139 Quad op-amp
Q30—ECG291
D17, D18—1N4001
D19, D20—1N4741A 11 volts, 1-watt, Zener
D21—1N4735A 6.2 volts, 1 watt, Zener
D22—1N4744A 15 volts, 1 watt Zener
D23—1N4750A 27 volts, 1 watt, Zener
LED1, LED2—Standard red LED
DISP1, DISP2—NSM39158 logarithmic bargraph display with driver (National)

Other components

S2, S3—SPDT

The following items are available from A&T Labs, Box 552, Warrenville, Illinois, 60555: Etched, drilled, plated-through PC boards, $22 each; Power transformer, $69 each; Set of 8 matched power FET's, $66; Drilled heatsink (type 512), $27. Add 5% shipping and handling, 12% for transformer. Illinois residents include 5-1/4% sales tax.

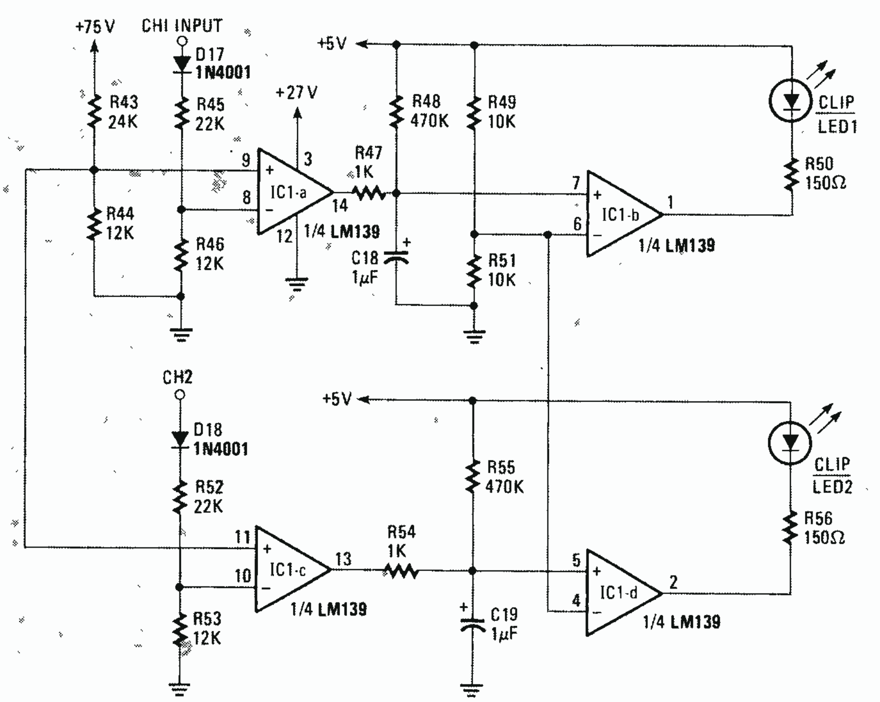

FIG 13—CLIPPING INDICATORS can be added to your amplifier, if desired.

STEREO FOR TV

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tral companding, we still have a problem with low-level signals (especially low-frequency, low-level signals). That's why the dbx system also uses *wideband* companding, which adjusts the level of all frequencies to keep the signal level high at all times. That companding method, whose response is shown in Fig. 11, reduces the dynamic range of the compressor-input signal by a factor of 2:1 dB—the low-level signals are boosted while high-level signals are reduced. The result is that the signal is always above the noise floor and always below 100% modulation (so as not to interfere with other parts of the spectrum).

The wideband expander in the receiver is essentially a mirror image of the compressor. It restores the signal to its proper amplitudes by reducing the level of low-level signals and increasing the level of high-level signals.

Stereo TV equipment

We mentioned earlier that many stations are stereo capable—or will be shortly. TV set manufacturers are getting set, too. You'll see sets with built-in stereo capabilitity, you'll see set-top decoders, and you'll also see Hi-Fi VCR systems tailored specifically for multichannel television sound. In cities with large bilingual populations, it's likely that we'll see SAP-only decoders.

Some of those devices are already on the market. And as stereo capability becomes a selling point, you're sure to see more. And you can be sure that **Radio-Electronics** will keep you up to date. **R-E**

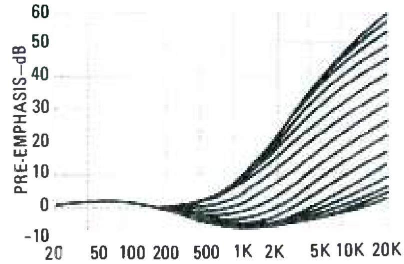


FIG. 10—THE COMBINATION OF fixed pre-emphasis and spectral compression leads to responses that can range from nearly flat to a high-frequency boost of 55 dB at 15 kHz!

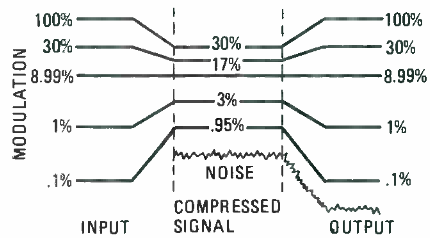
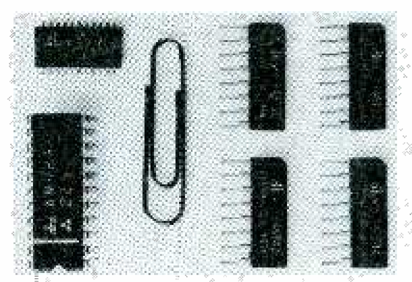


FIG. 11—WIDEBAND COMPANSION. The compressor reduces the dynamic range of input signals by increasing the level of low-level signals and reducing the level of high-level signals. The expander restores the signal to its original amplitude.



NOISE REDUCTION CIRCUITRY for the dbx system is available in three different IC configuration. The paper clip is shown to provide a sense of scale.

BUILT IN STEREO AND SAP DECODING are what make this 25-inch Zenith *Smart Set* different from most other TV's currently on the market. A stereo amplifier is built in, but audio-output jacks are also provided for greater flexibility.

TVRO BUYER'S GUIDE

continued from page 62

simply the signal being split into two parts.) So before we even consider cable losses, we have 8dB of loss. Now, what about those cable losses?

The cable losses will be considerable. Just how much will depend upon what frequencies are output by the downconverter. Remember that various receiver manufacturers offer different output-frequency ranges. And the top end or highest frequency in the range will have the greatest loss. Table 3 shows the typical losses for RG-6/U and RG-59/U coax at various typical "high-end" frequencies.

Note that the values given in Table 3 are only typical, and will vary (sometimes greatly) with the grade and manufacturer. It is important to understand that neither RG-6/U nor RG-59/U are really intended for use much above 900 MHz (try to locate manufacturer specifications above 900 MHz and you will quickly agree!) so the cheaper grades of RG-59/U "TV-hook-up cable" sold prepackaged by many of the national chain stores are apt to suffer far greater losses (per 100 feet) than what is quoted here. Our best advice is to stick to quality cables from manufacturers who will supply you with guaranteed loss-per-100 foot characteristics.

So, if we have lost 8dB of signal in our two splitters—and we can only lose 10 dB before we have a signal-level problem, it would appear we have 2dB left to lose in the cable. If our system uses a downconverter with an IF output of 950–1450, that means that we only can use about 21 feet of RG-6/U cable (total) for our hookup if we are to have satisfactory results at the high end of the band.

It is unlikely that we can reach all four sets in this system with no more than 21 feet of cable between the downconverter and the most distant TV receiver location. The solution is to use an amplifier.

As with the splitters we looked at earlier, line amplifiers intended for cable service often do not operate well at the frequencies output by satellite-TV downconverters, especially the higher frequencies. Fortunately there are a number of manufacturers that offer equipment specially intended for satellite-TV service.

Satellite-TV amplifiers typically have gains of 20dB, with a *slope* of 2 or 3 dB. For those unfamiliar with it, let's explain what is meant by slope. Remember that cable losses increase with frequency. A length of RG-6/U, for example, may have 9.5dB of loss at 1450 MHz, but it will have only 7.0dB of loss at 950 MHz. That's a 2.5dB differential, and the object of our system is to maintain not only a minimum of 0dBmV to each receiver, but

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TAPE STREAMER

continued from page 26

eter may be replaced, if desired, with a 1000-ohm resistor, as long as a jumper is added between the audio input terminal and the negative side of C1. That potentiometer is used only when extremely poor quality tape information requires an additional "tweak." In normal use, it will never be touched.

The use of IC sockets always seems to be a controversy. On the one hand, including them adds a potential long-term reliability problem; on the other, trouble shooting soldered-in IC's is a nightmare. Ultimately, it is the decision of the builder; but we recommend their use, as long as high-quality sockets are used.

Be careful to observe polarity on the diodes and electrolytic capacitors. The proper polarity is shown in Fig. 7. If you study the foil patterns, you'll notice that as an extra precaution, the PC board uses square pads to denote the positive end for the capacitors, and the cathode (banded) end of the diodes. The parts-placement pattern shows the transistor orientation for TO-92 packages. If you use substitute transistors, be careful that the right wires go into the right holes. The LED's must have long enough leads to reach the front panel.

The Streamer PC board may be mounted in its own enclosure (the one you see in the photos is available from the source mentioned in the Parts List). Alternatively, it can be mounted inside your computer, or even inside the tape deck. Mounting it inside the tape deck is a good idea if the tape deck supplies the Streamer power (as long as the deck won't be used for other recording!). Baud-rate switch S1 can be eliminated, since only one data rate will be used, and the DB-25 connector can be located on the rear of the deck. Locating the LED's may be a problem, though, depending on the configuration of your tape deck.

Installing the Streamer inside a computer is the least attractive option, as this precludes its use with other computers. One of the most important uses for the Streamer is to transfer files from one computer to another, and that cannot be accomplished if it is dedicated to one unit.

If the Streamer is to be mounted in its own enclosure, the procedure should be to: **1.** Assemble the PC card. **2.** Wire the DPDT switch (S1) to the card. **3.** Wire the connectors on the rear panel. **4.** Install the card and attach the rear panel wires. Follow the schematic for the proper connections to the DB-25 and the closed-circuit jack carefully. The power connection to DB-25 pin 25 is optional, and may be omitted if an external supply is to be used.

Troubleshooting

Initial trouble-shooting can be accomplished with an ordinary 20,000 ohms/volt (or better) volt-ohm-milliameter. Connect the VOM, on its highest current

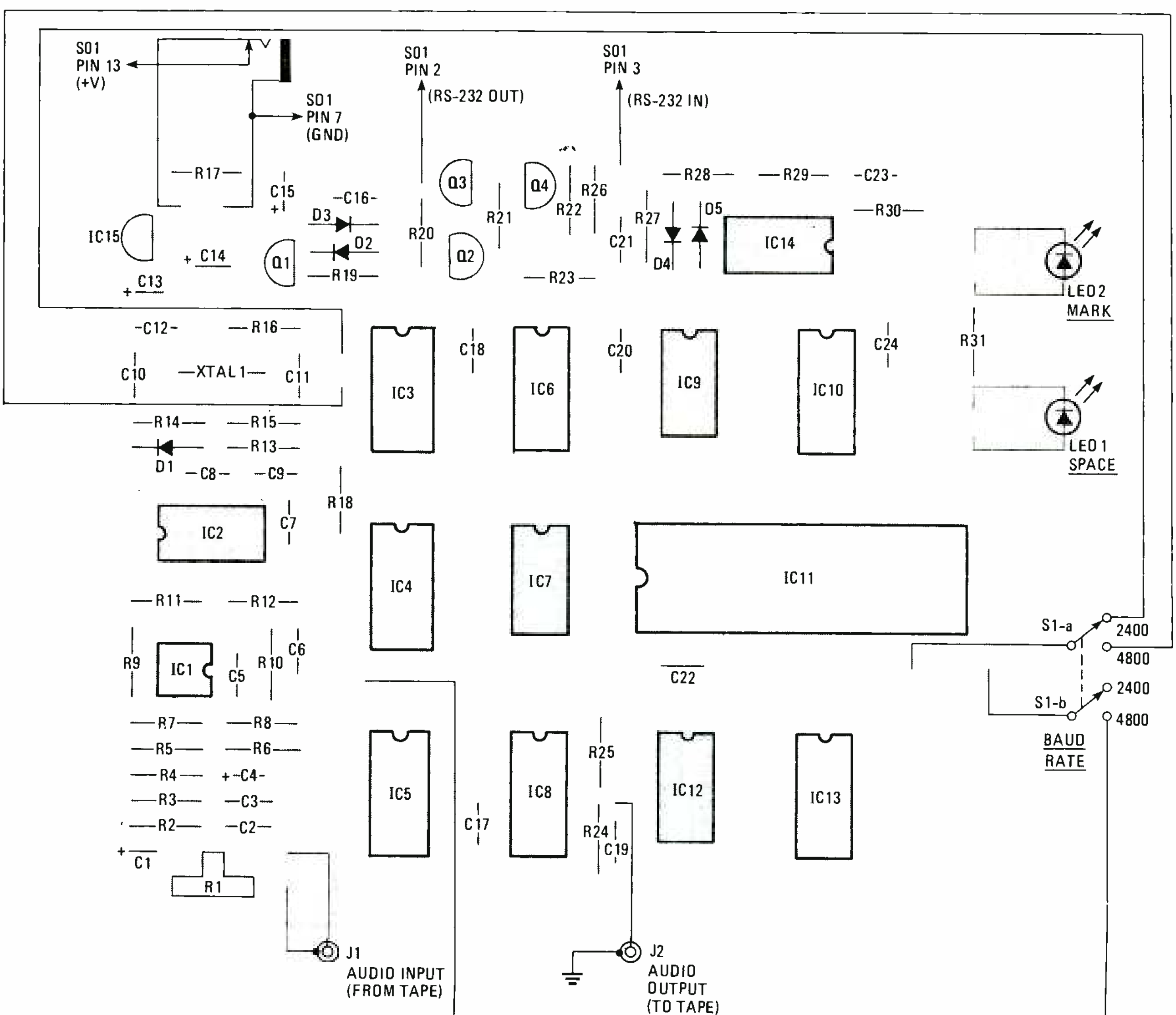

FIG. 7—PARTS PLACEMENT DIAGRAM for the Streamer shows both the on-board and off-board components.

scale, between the Streamer and its power supply. The streamer should draw in the range of 10–30 mA, and no LED's should be on. A very high current would indicate a short or a component in backwards, while a low current would indicate an open in either the power supply lines or the ground return.

If the above test is successful, remove the meter and connect the Streamer directly to the power supply. Measure the +5 volt supply at any convenient place. If it is above 5.25, or below 4.75, IC15 may be defective. Now measure the voltage at the end of R21 closest to Q2. There should be a negative voltage with a magnitude slightly less that that of the positive supply. If there is, that indicates the clock, the negative supply, and IC3 are functioning. Measure the the voltage on IC8, pin 15. If it reads about 2.5 volts, then the Manchester encoder is working.

Connect the encoder's AUDIO OUTPUT to the AUDIO INPUT. Adjust R1 to the normal full-on position. (If you are using the PC board, this is the full-clockwise position, viewed from the board's edge.) If the MARK LED comes on, both the encoder and decoder are working. That is about all the testing that can be done with a VOM. If everything looks good, it should work properly the first time.

If an oscilloscope is available for testing, much more extensive trouble shooting may be accomplished by referring to the schematic and the theory of operation. A word of caution, however; the bit sequence that appears at the output of IC12-b will be in a different order than that received. That "bit shuffling" was done to simplify the board layout. The received bits, then, will also be in a scrambled order until IC10 corrects them.

Using the Streamer

The Streamer is one of the simplest add-ons to any computer system. As long as your computer has an RS-232 port capable of a transmission rate of 4800 baud and a reception rate of 9600 baud, and as long as you have some sort of software to support storing and loading, you should have no problems. The tape machine can be just about anything—even a cheap portable (although, as we'll mention shortly, you'll sacrifice some performance). If you have a tape deck as part of your stereo system, it's probably ideal.

The supporting software may be the SAVE and LOAD commands with a BASIC interpreter, as long as they can be routed to an RS-232 port. BASIC programs can also be conveniently saved by LISTing them out to the Streamer, and read back in through an RS-232 port assigned as the console. The latter method has the advantage of allowing BASIC programs from different machines to be loaded, as the ASCII listing is, in effect, the same information that would be entered through the keyboard. The same can be done with source files, or, for that matter, any ASCII file.

Machine-language program storage and retrieval can be handled by any of a great many approaches, at least one of which is probably resident in the computer you now use. The routine the author uses on his system, like many others, transmits in sequence a delimiter stream, a load address, 255 bytes of data, and then a checksum. That is followed immediately by the next load address, data, checksum, and so forth, until all the data is done. When the tape is played back to the computer, each checksum is compared with a calculated checksum, and any error causes the routine to halt.

If you ever run across data errors when loading programs back into your computer, the cause is probably dirty tape heads. Simply cleaning the heads should eliminate the problem.

When configuring your RS-232 port, remember that the Streamer works with 8-bit data words. Those eight bits can be all data, seven data and one parity bit, or seven bits, no parity, and at least two stop bits. The only real requirement is that start bits must be at least nine bit-times apart, such as with eight data bits and one stop bit. In storing 7-bit ASCII files, it is normal to follow with a parity bit. The Streamer will treat the eighth bit as part of the data, faithfully recording it and playing it back. The Streamer itself does no parity checking; it simply records the data and returns what is presented to it.

The audio output of the Streamer is designed to present a signal compatible with the audio input of a hi-fi type tape deck. Since modern decks have input-level controls, the control should be adjusted for best performance. Unlike conventional cassette interfaces, that adjustment is not critical at all. To determine your optimum adjustment, use the tape counter to record segments at various settings, then play them back, noting any recovery errors. The errors should occur at the extremes of the level control settings. Simply set the control approximately half way between where errors occurred, and you're under way.

The Streamer can be used with low-cost portable tape recorders, with some loss of performance: Because of their lower bandwidth capability, the Streamer must be operated at 2400 baud instead of 4800 (which is usually possible with most modem hi-fi decks).

The audio signal out of the streamer is about 0.9 Volt peak to peak, which suits most decks just fine. But you'll probably have to reduce that level if you want to apply it to a portable recorder. You can do that with either a resistive voltage divider at the recorder's input, or by simply reducing the value of R24: Try values in the 100- to 1000-ohm range.

Whether you use the Streamer for primary data and program storage, disk backup, or to exchange programs with other computers, it will undoubtedly be a welcome addition to your computer system. **R-E**

PARTS LIST

All resistors ¼ watt, 10% unless otherwise noted

R1—1000 ohms, PC-mount, trimmer potentiometer
R2, R5, R6, R11, R16, R17, R20, R28, R29—1000 ohms
R3, R4, R7, R8, R13, R14, R18, R19, R22, R23, R25, R26, R30—10, 000 ohms
R9—1 Megohm
R10—100,000 ohms
R12, R21, R27—47,000 ohms
R15—10 Megohms
R24—2200 ohms
R31—330 ohms

Capacitors

C1, C4, C13—10 µF, 25 volts, electrolytic
C2, C21—0.001 µF, ceramic disc
C3, C12, C16—0.1 µF ceramic disc
C5, C7, C17, C18, C20, C22, C23, C24—0.01 or .1 µF bypass capacitors (not shown in schematic)
C6, C10—20 pF, ceramic disc
C8, C9—250 pF ceramic disc
C11—5 pF, ceramic disc
C14—100–330 µF, 25 volts, electrolytic
C15—47–220 µF, 25 volts, electrolytic
C19—0.01 µF, ceramic disc

Semiconductors

IC1—LM392 or LM2924 op-amp/comparator
IC2—4070 or 74C86 quad XOR gate
IC3—4040 12-stage binary ripple counter
IC4, IC6—4029 presettable up/down counter
IC5—4520 dual 4-bit synchronous counter
IC7—4011 quad 2-input NAND gate
IC8—4027 dual J-K flip-flop
IC9, IC12—74C74 dual D-type flip-flop
IC10—4015 dual 4-bit static shift register
IC11—6402 CMOS UART (Intersil)
IC13—4021 8-stage static shift register
IC14—LM339 quad comparator
IC15—78L05 low power 5-volt regulator
D1–D5—1N914 or similar
D6, D7—standard red LED
Q1, Q3—2N3904
Q2, Q4—2N3906
XTAL1—2.4576 MHz crystal

MISCELLANEOUS: PC board, enclosure, DPDT switch, DB25 connector, phono jacks for tape deck connectors, hardware, solder, etc.

The following are available from Stone Mountain Engineering Co., PO Box 1573, Stone Mountain, GA, 30086: Printed circuit board, double-sided with plated-through holes, solder masked and silkscreened, for $28; Enclosure, with all holes punched and legends silkscreened, $16; Both PC board and enclosure for $40. All orders must include $1.50 shipping and handling, and Georgia residents please enclose 3% sales tax.

BATTERIES

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fails, the diode is forward biased and the NiCd batteries provide power to the load. The calculations for finding the value of R and the considerations for choosing the diode are exactly the same ones we discussed for our simple charger. There are other, more elaborate schemes for using rechargeable batteries like this, but they all use this approach. Diodes are used to steer the current where you want it and the biasing of the diodes is switched by the presence or absence of the main power supply.

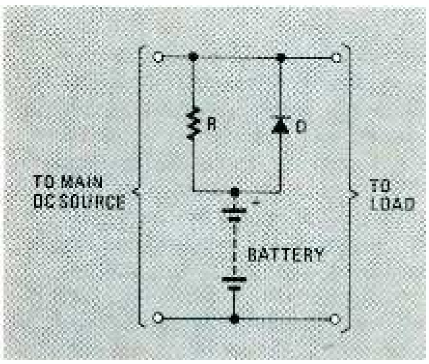

FIG. 12—ONE OF THE MOST POPULAR applications for rechargeable batteries is backing up power supplies.

We now come to the question of which battery type you should use. Well, the answer is, as we saw with disposable batteries last month, it depends. As a general rule, lead-acid batteries are used where the current draw is going to be heavy and NiCd's are used where it's not. Now I know that these are all relative terms but, like I said, it depends.

For practical purposes, let's just say that if the current draw is going to be consistently in the multi-ampere range, go for lead-acid. If it's under an amp, look at NiCd cells. The relative merits of each system are summed up in Table 6 and the voltage-discharge curves for some of the various batteries are shown in Fig. 13. I've put in the curves for some of the lithium-based batteries as well as the zinc-carbon ones so you can make an overall comparison.

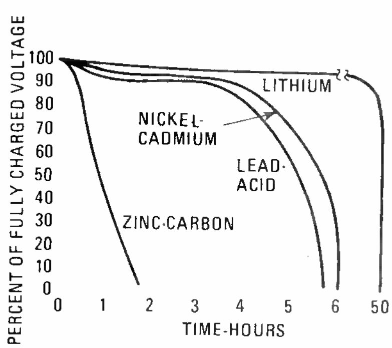

FIG. 13—VOLTAGE DISCHARGE CURVES for various types of batteries discharged at the 0.2C rate. Note the break in the hours scale.

TABLE 7—BATTERY MANUFACTURERS

Lithium batteries

Altus Corporation
1610 Crane Court
San Jose, Ca. 95112

Tadiran
6312 Variel Avenue
Woodland Hills, Ca. 91367

Varta Batteries, Inc.
150 Clearbrook Road
Elmsford, N.Y. 10523

Lead-acid batteries

Technacell
2117 South Anne St.
Santa Anna, Ca. 92704

Eagle Pitcher Ind., Inc.
PO Box 130
Seneca, Mo. 64865

Gould Inc.
931 N. Vandalia St.
St. Paul, Minn. 55114

Nickel-cadmium batteries

Gould Inc.
931 N. Vandalia St.
St. Paul, Minn. 55114

Varta Batteries, Inc.
150 Clearbrook Rd.
Elmsford, N.Y. 10523

General Electric
Battery Business Dept.
PO Box 861
Gainesville, Fl. 32602

By now you should know enough about all the different battery chemistries to make an intelligent decision as to which battery system (or combination of systems) is best for your application. And if you're not exactly sure, you should have enough information to know what the right questions are.

Battery manufacturers will be more than happy to send you data sheets, catalogs, and application notes so you can find out whatever you want to know. Table 7 is a good beginning list of companies you can contact for information. Don't hesitate to write to them—they know more than you do and can save you lots of time and trouble. And a postage stamp is a pretty cheap insurance policy when it comes to saving twenty dollars worth of batteries. **R-E**

TVRO BUYER'S GUIDE

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to also attempt to keep the level "balanced" (i.e. the same) at the input to each receiver and on each channel. A "sloped amplifier" has 2 to 3 dB more gain at 1450 MHz than it does at 950 MHz. That sloped gain acts to compensate for the expected additional cable losses at the higher frequencies.

In summary, many of the original problems of TVRO reception have been eliminated by newer equipment designs. Everything about TVRO equipment has become more consumer/user "friendly" in the past 18 months, and the industry is rapidly approaching a "mature" design level from which innovation will switch to product efficiencies rather than product features. Most equipment now arrives on your doorstep with reasonably adequate installation instruction manuals, and most equipment now carries at least a one-year OEM warranty. **R-E**

EQUIPMENT REPORT

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The Alden Weatherchart Recorder (which is also available in kit form) is supplied with two paper cassettes, three spare stylus belts, the audio matching transformer, two spare fuses, and a selection of notably good manuals. The operator's manual is superb; it is clear, concise, unwordy, and is well illustrated. Also supplied is a directory of worldwide facsimile stations, a guide to understanding radiofacsimile weather charts, and a technical manual that includes the step-by-step kit assembly.

The kit version is priced at $995, the wired version (the model we tried) sells for $1995. **R-E**

ADVERTISING INDEX

Electricity and water don't mix. At least not in our Heavy Duty Digital Multimeters. Because these Oops Proof™ instruments are protected by a system of seals to ensure contamination-free dependability in even the cruddiest conditions.

Other abuse-proof features include the best mechanical protection ever built into a precision Digital Multimeter. In fact, every one of our Oops Proof multimeters will survive a drop from ten feet onto a concrete surface!

All the Heavy Duty series meters measure up to 1000 volts AC and 1500 volts DC, with full overload protection to those maximum voltages even on the lowest range settings. Overload circuitry also provides transient protection to 6KV on all voltage ranges and up to 600 volts on all resistance ranges.

We also invented a unique, long-life rotary switch for our Digital Multimeters. You can actually feel the difference just by rotating the function selector knob.

You'll find these features in a full line of Heavy Duty DMMs that offer a 4½ digit readout, 0.05% VDC accuracy, a 10-amp current range, a 2000-hour battery life, diode test, true RMS and temperature measurement. All this and a no-questions, one-year warranty.

You'll want to try one out, of course, so drop into your nearest electronics distributor and drop one.

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