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Whether you're trying to find your way to an unfamiliar location or need assistance in an emergency, ICOM mobiles help you find your way. ICOM's dependable mobiles steer you to a friendly voice or a helping hand.

Most Popular Mobiles.
ICOM's popular mobiles include the 2-meter IC-28A and IC-28H, 220MHz IC-38A, 440MHz IC-48A and 2-meter/70cm dual band IC-3200A.

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Store frequency, offset and tone, with an offset check button on the front panel. The IC-3200A features 10 fully tunable memories.

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- DTMF Mic Included

Options.
Options include the UT-28 digital coded squelch, SP-10 speaker, HS-15/HS-15SB boom mic and PTT switchbox and PS-45 AC power supply.

ICOM Mobiles.
Don't be lost without them. Find them at your local ICOM dealer.

"I feel any company willing to build radios as survivable as my IC-28A deserves my ham radio dollars. . . ."

Jonathan Stan AH6JU
After tropical storm in which he was instrumental in the rescue of stranded residents. Kahului, Hawaii

IC-28A and IC-28H
Rx 136-174MHz
Tx 140.1-150MHz
IC-38A
220-225MHz
IC-48A
440-450MHz
IC-3200A
140-150MHz and 440-450MHz
THE ALL NEW PRIVATE PATCH IV BY CSI HAS MORE COMMUNICATIONS POWER THAN EVER BEFORE

- Initiate phone calls from your HT or mobile
- Receive incoming phone calls
- Telephone initiated control...
  - Operate your base station with complete control from any telephone
  - Change frequencies from the controlling telephone
  - Selectively call mobiles using regenerated DTMF from any telephone
  - Eavesdrop the channel from any telephone
  - Use as a wire remote using ordinary dial up lines and a speaker phone as a control head.

The new telephone initiated control capabilities are awesome. Imagine having full use and full control of your base station radio operating straight simplex or through any repeater from any telephone! From your desk at the office, from a pay phone from a hotel room, etc. You can even change the operating channel from the touchpad!

Our digital VOX processor flips your conversation back and forth fully automatically. There are no buttons to press as in phone remote devices. And you are in full control 100% of the time!

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The importance of telephone initiated control for emergency or disaster communications cannot be overstated. Private Patch IV gives you full use of the radio system from any telephone. And of course you have full use of the telephone system from any mobile or HT!

To get the complete story on the powerful new Private Patch IV contact your dealer or CSI to receive your free four page brochure.

Private Patch IV will be your most important investment in communications.

| Connects to MIC and ext. speaker jack on any radio. Or connect internally if desired. |
| Connects to any HT. (Even those with a two wire interface.) |
| Can be operated simplex, through a repeater from a base station or connected directly to a repeater for semi-duplex operation. |
| 20 minutes typical connect time |
| Made in U.S.A. |

OPTIONS
1. ½ second electronic voice delay
2. FCC registered coupler
3. CW ID chip

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TM-721A
Deluxe FM dual bander

The Kenwood TM-721A redefines the original Kenwood "Dual Bander" concept. The wide range of innovative features includes a dual channel watch function, selectable full duplex operation, 30 memory channels, extended frequency coverage, large multi-color dual digital LCD displays, programmable scanning, and more with 45 watts of output on VHF and 35 watts on UHF. TM-721A—Truly the finest full-featured FM Dual Band mobile transceiver!

- Extended receiver range (138.000-173.995 MHz) on 2 meters; 70 cm coverage is 438.000-449.995 MHz. (Specifications guaranteed on Amateur bands only. Two meter transmit range is 144-148 MHz. Modifiable for MARSI/CAP Permits required.)
- 30 multi-function memory channels: 14 memory channels and one call channel for each band store frequency, repeater offset, CTCSS, and reverse. Channels "A" and "B" establish upper and lower limits for programmable band scan. Channels "C" and "D" store transmit and receive frequencies independently for "odd splits."

Optional Accessories:
- RC-10 Multi-function handset/remote controller
- PS-430 Power supply
- TSU-6 CTCSS decode unit
- SW-100B Compact SWR/power/volt meter
- SW-200B Deluxe SWR/power meter
- SWT-1 2m antenna tuner
- SWT-2 70 cm antenna tuner

Compact mobile speaker = SP-50B Deluxe mobile speaker = PG-2N DC cable = PG-3B DC line noise filter = MC-60A, MC-60, MC-85 Base station mics = MA-4000 Dual band mobile antenna (mount not supplied)

- Separate frequency display for "main" and "sub-band."
- 45 Watts on 2 meters, 35 watts on 70 cm. Approx. 5 watts low power.
- Call channel function. A special memory channel for each band stores frequency, offset, and sub-tone of your favorite channel. Simply press the CALL key, and your favorite channel is selected!
- Automatic Band Change (A.B.C.) Automatically changes between main and sub-band when a signal is present.
- Dual watch function allows VHF and UHF receive simultaneously.
- CTCSS encode/decode selectable from front panel or UP/DOWN keys on microphone. (Encode built-in, optional TSU-6 needed for decode.)
- Balance control and separate squelch controls for each band.
- Dual antenna ports.
- Full duplex operation.
- Programmable memory and band scanning, with memory channel lock-out and priority watch function.
- Each function key has a unique tone for positive feedback.
- Illuminated front panel controls and keys.
- Dimmer control.
- 16 key DTMF mic. included.
- Handset/remote control option (RC-10).
- Frequency (dial) lock.
- Supplied accessories: 16-key DTMF hand mic., mounting bracket, DC cable.

Using service manual, available for all Kenwood transceivers and mobile transceivers. Specifications, features, and prices are subject to change without notice or obligation.

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March 1988
I was just dreaming the other day.

Ya know, a big push is being made to get Novices on 220 MHz. Thousands of dollars are being spent on promotional campaigns, training programs, and the like. Volunteer instructors, the heroes of Amateur Radio, have missed countless meals, sleep, and other obligations to bring the message of Amateur Radio to potential new Novices.

As I turn the pages of Amateur magazines from around the world, I see numerous examples of some of the finest solid-state engineering ever done — hf, VHF, UHF and above; multiband, multimode — everything.

But...

In this age of Novice enhancement, to get on 2 and 1.35 meters, you need to buy two different radios. Why?

For years, radios have been available that cover both 2 and .75 meters. Technically it is relatively easy to do: divide by 3 (440 MHz/3 = 146.67 MHz). A simple tripler circuit in the PLL and a few rf deck modifications and you’re ready to go. While in many areas .75 meters is a very useful band, up here in the hinterlands repeater coverage is spotty at best. I tried a multiband radio for a while but 440 really did little for me. On the other hand, 1.35 meters has very interesting possibilities. Coverage is more like 2 meters and there are several very good 220-MHz machines in the area.

With all the advances in solid-state design, it really shouldn’t be too hard to come up with a single box to cover both 2 and 1.35 meters. The tricky part will be engineering the PLL. My guess is that the rf deck would be relatively straightforward and easy to build. However, I will leave that to the experts.

Besides tapping a potentially large market, this new radio would stimulate additional activity on both bands and, through increased usage on 220 MHz, help Novices join in the mainstream of Amateur activity.

We have a responsibility to ensure that Novices learn to be the good hams we want them to be. All too often it has been said that giving Novices 1.35 meter privileges does not enhance the Amateur licensing one bit. Wrong. Novices are using their voice privileges daily around the United States. It has already been shown that they can be integrated into a broader spectrum of Amateur frequencies without a major disruption in overall operation.

How about it, manufacturers? Can you do it? You’ll sell a lot of radios and get more of us on 220 MHz. It’s a win-win situation.

What do you readers think? I’m very interested. Let me know.

J. Craig Clark, N1ACH
Assistant Publisher
Affordable DX-ing!

**TS-140S**

HF transceiver with general coverage receiver.

Compact, easy-to-use, full of operating enhancements, and feature packed. These words describe the new TS-140S HF transceiver. Setting the pace once again, Kenwood introduces new innovations in the world of “look-alike” transceivers!

- Covers all HF Amateur bands with 100 W output. General coverage receiver tunes from 50 kHz to 35 MHz. (Receiver specifications guaranteed from 500 kHz to 30 MHz.) Modifiable for HF Mars operation. (Permit required.)
- All modes built-in. LSB, USB, CW, FM and AM.
- Superior receiver dynamic range Kenwood DyMix™ high sensitivity direct mixing system ensures true 102 dB receiver dynamic range.

- New Feature! Programmable band marker. Useful for staying within the limits of your ham license. For contesters, program in the suggested frequencies to prevent QRM to non-participants.
- Famous Kenwood interference reducing circuits. IF shift, dual noise blankers, RIT, RF attenuator, selectable AGC, and FM squelch.

**TS-680S**

All-mode multi-bander

- 6m (50-54 MHz) 10 W output plus all HF Amateur bands (100 W output).
- Extended 6m receiver frequency range 45 MHz to 60 MHz. Spec'd guaranteed from 50 to 54 MHz.
- Some functions of the TS-140S except optional VOX (VOX-4 required for VOX operation).
- Preamp for 6 and 10 meter band.

- M. CH/VFO CH sub-dial. 10 kHz step tuning for quick QSY at VFO mode, and UP/DOWN memory channel for easy operation.
- Selectable full (QSK) or semi break-in CW.
- 31 memory channels. Store frequency, mode and CW wide/narrow selection. Split frequencies may be stored in 10 channels for repeater operation.
- RF power output control.
- AMTOR/PACKET compatible!
- Built-in VOX circuit.
- MC-43S UP/DOWN mic. included.

Optional Accessories:

- AT-130 compact antenna tuner
- AT-250 automatic antenna tuner
- HS-5/HS-6/HS-7 head phones
- IF-322C/IF-10C computer interface
- MA-5/VF-1 HF mobile antenna (5 bands)
- MB-435 mobile bracket
- MC-43S extra UP/DOWN hand mic.
- MC-55 (8 pin) gooseneck mobile mic.
- MC-60A/MC-80/MC-85 desk mics
- PG-2S extra DC cable
- PS-430 power supply
- SP-40/SP-508 mobile speakers
- SP-430 external speaker
- SW-100A/SW-200A/SW-2000 SWR power meters
- TL-922A 2 kW PEP linear amplifier (not for CW QSK)
- TU-8 CTCSS tone unit
- YG-455C-1 1500 Hz deluxe CW filter YK-455C-1

New 500 Hz CW filter.

Complete service manuals are available for all Kenwood transceivers and most accessories. Specifications, features, and prices are subject to change without notice or obligation.

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2201 E. Dominguez St., Long Beach, CA 90810
P.O. Box 22745, Long Beach, CA 90801-5745
A Passionate Plea

What'sa matter? Haven't we supplied you with enough information on matching your transmitter to your antenna without having to put a full gallon and a half on the air while loading up? Must you have that last milliwatt going into your antenna system? Don't you hear the cries of anguish from 30 guys writhing in pain as they scramble to cut back on their gain controls after having fully advanced it for that extremely weak HL5?

About once a year it seems necessary to remind a few of you that there are other ways to make certain that maximum power transfer occurs during operation, without having to first load up on the air.

Let's take it in steps. First let's find that 50-ohm setting on your amplifier or exciter. There is where a dummy load comes in. There are several good commercial units available or you can make one with a 50 or 100 watt noninductive resistor immersed in a gallon can of oil. Second, connect your transmitter or amplifier to this 50-ohm load (put a power meter in line if you happen to have one) that will take the power for at least a few seconds. Then adjust the tune and load controls until your output and other meter indications are what they should be for the given operating mode and tube ratings. Keep in mind that you don't want your SSB performance to suffer by trying to get out that last possible watt of power. Once you've determined the correct settings mark them with tape or crayon, or jot down the numbers off the apron of the knobs or mechanical readout for each band and segment that you intend to operate.

Next, get or make a noise bridge. (We've had several good construction articles like "A Modern Noise Bridge", March 1983, page 50.) Set it for 50 ohms resistive and 0 ohms reactive — or whatever the characteristic impedance of your system is. Connect it to the coaxial output of the transmatch or antenna coupler (the one that's marked 'to the transmitter') and connect the other port of the bridge to your receiver (transceiver). For heaven's sake, don't apply rf power from your transmitter unless you have stock in the noise bridge company. Adjust your antenna coupler until you hear minimum noise in the receiver. Mark down these settings and reconnect your transmitter to your antenna. You should be pretty darn close to match at this point.

I can hear you muttering, "Why did the editor waste all this space on this subject? This is ham radio magazine and the majority of readers are technically sharp and know this and other matching procedures forwards and backwards." If this is true, why do I hear so many carriers in the extra and advanced portion of the bands?

One more small point while I've got your attention: PLEASE ask first to see if the frequency is occupied before starting a call — CQ, sked, or otherwise. It's possible that while you might not hear the DX station, others do and your bodacious signal will obliterate the weak signals. Recently a certain W2, hell-bent on working a particular contest, called probably 10 CQs in a row without raising any DX while right underneath him an LU2, several JAs, and a Korean station were on. This occurred on 3799 and I'm sure he was oblivious to it. If he had bothered to ask, I can assure you that at least one DX'er would have apprised him of the situation.

I could go on about leaving DX windows clear during contests for very weak signal work, unless of course you are the proverbial shooting fish in the barrel type, but I think you've heard enough from me for this issue. Just please be easy on your fellow ham's ears — those nerves just don't regenerate!

Rich Rosen, K2RR
Editor-in-Chief

March 1988
Kenwood brings you a wide range of 220 MHz gear designed for every need. Choose from two types of mobile and two types of HT. The TH-315A is a full-featured HT covering 220-225 MHz. Ten memory channels and 2.5 watts of power (5 W with PB-1 or 12 V DC.) Uses the same accessories as the TH-215A for 2 meters or TH-415A 440 MHz. For truly “pocket portability,” choose the TH-31BT, a thumb-wheel programmable, 1 watt unit. For mobile use, select the TM-321A or TM-3530A.

The TM-321A is the 25 W, 220 MHz, 14-memory version of the super popular, super compact TM-221A. The 25-watt TM-3530A has 23 memories, a 15 telephone number memory and auto dialer. Direct keyboard frequency entry and front panel DTMF pad enhances operating convenience. Novice to Amateur Extra, these transceivers will put everyone on the air “Kenwood Style”!

The TM-321A comes with 16-key DTMF mic. A complete line of accessories is available for all models. Complete service manuals are available for all Kenwood transceivers and most accessories. Specifications and prices are subject to change without notice or obligation.
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Box 494, Miss. State, MS 39762
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printed – such as some news
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pictures and maps.

**Automatic** sync and stop lets you set
it and leave it for no hassle printing.

**You** can save FAX pictures and
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**Pictures** and maps can be printed to
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and compatible with the MFJ-1284 Starter
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**You** can transmit FAX pictures right
off disk and have fun exchanging and
collecting them.

**Slow Scan TV**
The MFJ-1278 introduces you to the
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pictures from thousands of SSTVers all
over the world but you can send your
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**You** can print slow scan TV pictures on
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lights and a camera for a casual contact.

**You** can save slow scan pictures on disk
from over-the-air and terminal program
lets you save ASCII files.

**The MFJ-1278** transmits and receives
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format SSTV pictures using two levels.

**Contest Memory Keyer**
Nothing beats the quick response of
a memory keyer during a heated contest.

**You** score valuable contest points by
completing QSOs so fast you'll leave your
competition behind. And you can snap
type DX by slipping in so quickly you'll
crack up the operators.

**You** get automatic operation with
delayed memories, self-completing dots
dashes and jamproof spacing.

**Message** memories let you store contest
RST, QTH, call info – everything you
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save precious time and work more QSOs.

**You** get automatic incrementing serial
numbering. In a contest it can make the
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**MFJ shatters the 6 mode barrier and the price barrier**

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. . . 7 digital modes . . . for an affordable $249.95

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for the IBM or compatible, $19.95 each.

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any amateur digital mode.

With **MFJ's** super clone of the industry
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Radio Magazine ("HF Modem Performance
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DCC operation under all tested conditions
than the other modems tested.

**Hardware** DCC gives you more QSOs
because you get reliable carrier
detection under busy, noisy or weak
conditions.

A hardware HDLC gives you full
duplex operation for satellite work or
for use as a full duplex digipeater.
And, it makes possible speeds in excess of
56 K baud with a suitable external modem.

Good news for SYSOPS! New software
lets the MFJ-1278 perform flawlessly as
a WORL/WA7MBL bulletin board TNC.

**Baudot RTTY**

You can copy all shifts and all
standard speeds including 170, 425 and
800 Hz shifts and speeds from 45 to 300

**fledged weather maps on your printer.**

Other interesting FAX pictures can also be
printed – such as some news
photographs from wire services.

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printer will print a wealth of interesting
pictures and maps.

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used to have to repeat over and over. You'll
save precious time and work more QSOs.

**You** get automatic incrementing serial
numbering. In a contest it can make the
difference between winning and losing.

A weight control lets you penetrate
QRM with a distinctive signal and lets your
transmitter send perfect sounding CW.
Dear Rich:

I have a bone to pick with you, Rich. The January issue of ham radio, somehow conveys to me that your sense of priorities in the selection of articles to be printed in the magazine is all screwed up.

Over the past few weeks, I have been playing around with various CW programs for my C-64. I was never pleased with the results. Being a rank novice at programming, I struggled to get the dash/dot ratios and the word spacings to my satisfaction. When all of a sudden as I was paging through the recent issue of ham radio, I find an article that perhaps would give me what I sought — a solution to the rather “sloppy” sending of computer-ized CW programs. You can imagine my disappointment when the program was not listed at the end of the article.

Now I can appreciate your problem about space in the magazine. With your organization no longer providing mailing covers on the magazine, and with the magazine arriving tattered, torn and dog-eared, I can really empathize with you. So I was ready to let sleeping dogs lie, until I continued on through the issue and found the most useless waste of print in years in an article entitled “Build a QSO ‘Beeper’”.

Now, really Rich, we need this sort of thing on the bands like we need another hole in the head. Can’t you imagine what a crowded band like 20 meters or 75 meters would sound like? It would remind me of trying to go to sleep on a hot night when all the crickets are chirping away. Once again I could forgive you for a lapse in good judgment, but not for wasting six good pages on the beeper article when you couldn’t spare seven pages for a decent computer CW program!

This sort of thing has put me on hold for a few weeks because I must now wait for a copy of the program from you or pay 8 bucks for a programmed disk.

You must realize by now, that your readership is of a high caliber and will not put up for long with articles of this type.

Tony Sivo, W2FJ
Plainsboro, New Jersey 08536

on the other hand...

Dear HR:

Congratulations on your January 1988 edition. Every article and item was crammed with information at just the right level for we non-engineers, non-appliance operator Amateurs, and hobbyists who still build, experiment, and improve our equipment. Hope you can keep it up.

John Browning, Buena Park, CA 90620

Dean LeMon, KR0V sure is! Dean got active in Amateur Radio when he was 16 years old and earned his Extra Class license in less than four years! “It’s a fascinating hobby and a great way to meet all kinds of new people from all over the world.”

Dean has cerebral palsy and got started in Amateur Radio with help from the Courage HANDI-HAM System. The HANDI-HAM System is an international organization of able-bodied and disabled hams who help people with physical disabilities expand their world through Amateur Radio. The System matches students with one to one helpers, provides instruction material and support, and loans radio equipment.

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high dynamic range mixing with the Si8901

Extends intermod HF/VHF performance at lower drive

The dynamic range of a mixer is intimately related to how well its intermodulation products are suppressed, how well the mixer can handle high-level signals, and its overall noise figure. Whether a mixer offers conversion gain or loss is secondary to the benefits derived from a high dynamic range. In fact, conversion gain simply transfers the problems associated with dynamic range from the mixer to subsequent amplifier stages.

Until now, most mixers sporting a high dynamic range have required a correspondingly high local oscillator drive, as shown in the performance comparison in fig. 1. The popular diode-ring double-balanced mixer (DBM), shown in fig. 2, often requires the local oscillator power to exceed the signal compression level by at least 6 dB.

The Siliconix Si8901 DBM (fig. 3) is a monolithic quad-MOSFET ring demodulator especially suited for HF and low VHF operation where, as a commutation (switching) mixer, it is capable of two-tone, third-order input intercepts exceeding +37 dBm and a 2-dB signal overload compression and desensitization of +30 dBm — all at a local oscillator drive level of only +17 dBm (50 mW)! An additional benefit of this low local oscillator drive results when, in combination with the traditionally high interport isolation afforded by DBM design, little re-radiated power exits the mixer through the signal port.

The Si8901 is available in the hermetic TO-99 package, suitable for full military applications, as well as in a surface-mount SO-14, which is useful for modern industrial and Amateur applications where high dynamic range is mandatory.

theory of operation — conversion efficiency

Unlike the diode-ring mixer, the commutation mixer relies on the switching action of the quad-MOSFET elements to effect mixing action. Consequently, the Si8901 is, essentially, a pair of switches reversing the phase of the signal at a rate determined by the local oscillator frequency. Ideally, we would expect little noise. Since the MOSFET exhibits a finite on-resistance, the conversion efficiency is expressed as a loss. This loss results from two related factors: first, the \( r_{DS(on)} \) of the MOSFETs relative to both the signal and i-f impedances, and second, signal conversion to undesired frequencies.

The effect of \( r_{DS(on)} \) on both the signal and the i-f impedances \( R_g \) and \( R_L \), respectively may be derived from analysis of an equivalent circuit (fig. 4), assuming the local oscillator drive is an idealized square wave. The term \( 4/\pi^2 \) is the power function of the Fourier series of an idealized square-wave excitation.

Conversion loss for an ideal mixer with the image and sum frequency (RF + LO) ports shorted may be expressed in terms of \( r_{ds} \) (on), \( R_g \), and \( R_L \) as follows:

\[
L_c = 10 \log \left( \frac{r_{DS(on)}}{R_g + r_{DS(on)}} + \frac{R_L + r_{DS(on)}}{\pi^2 R_g R_L} \right) \tag{1}
\]

If we let \( r_{DS(on)} = 0 \) and resistively-terminate the image and sum frequency ports the minimum attainable conversion loss reduces to

\[
L_c = 10 \log \frac{4}{\pi^2} \text{ dB} \tag{2}
\]

which computes to \( L_c = -3.92 \text{ dB} \). In a practical sense we need to add 3.92 dB to the results of eqn. 1 or fig. 5 to obtain the true conversion loss.

By Ed Oxner, KB6OJ, Applications Engineer, Siliconix Inc., Santa Clara, California 95054
Equation 1 plotted for various ratios of $R_g$, $R_L$, and $r_{DS(on)}$ (fig. 5) illustrates how seriously the on-resistance of the MOSFETs affects the conversion loss.

intermodulation distortion

Unbalanced, single-balanced, and double-balanced mixers are distinguished by their ability to reject spurious frequency components selectively, as defined in table 1. In the majority of mixer applications, the most damaging intermodulation distortion products (IMD) are those attributed to odd order and, in particular, those identified as the third order (IMD3). Although the DBM outperforms the single-balanced mixer, a more serious source of intermodulation products results when the local oscillator excitation departs from the idealized square wave. This phenomenon is easily recognized by a careful examination of fig. 6, which shows the effect of sinusoidal local oscillator voltage on varying transfer characteristics. Since optimum IMD performance demands that the switches, of a commutation mixer operate in a 50-percent duty cycle (i.e., fully on and fully off for equal times), some offset voltage is necessary.

Walker\(^1\) has derived an expression showing the predicted improvement in the relative level of two-tone, third-order IMD as a function of the rise and fall times of the local oscillator waveform.

$$IMD = 20 \log \left( \frac{t_{r/f} V_c/V_s}{V_c/2} \right) dB$$

where $V_c$ is the peak-to-peak local oscillator voltage $V_s$ is the peak signal voltage $t_r$ is the rise and fall time of $V_c$ $\omega_{LO}$ is $2\pi f_{LO}$ where $f_{LO}$ is the local oscillator frequency

Equation 3 shows that by lowering $R_g$ (which, in turn, decreases the magnitude of $V_S$) IMD performance is improved. Likewise, increasing the local oscillator voltage, $V_c$, improves IMD performance. Finally, if we can provide idealized square-wave excitation, we achieve the perfect mixer! Additionally, we see that low-side injection is more efficient than high-side injection.

Further justification for square-wave local oscillator drive is an additional fault of sinusoidal excitation. Whenever the exciting wave approaches zero crossing at half-period intervals, the FETs, in effect, lose

<table>
<thead>
<tr>
<th>single-balanced</th>
<th>double-balanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$, $3f$, $5f$, $f_1 + f_2$, $f_1 + 3f_2$, $f_1 + 5f_2$, $2f_1 + f_2$, $3f_1 + f_2$, $3f_1 + 3f_2$, $4f_1 + f_2$, $5f_1 + f_2$</td>
<td>$f_1 + f_2$, $f_1 + 3f_2$, $f_1 + 5f_2$, $2f_1 + f_2$, $3f_1 + f_2$, $3f_1 + 3f_2$, $4f_1 + f_2$, $5f_1 + f_2$</td>
</tr>
</tbody>
</table>
Table 2. Comparison of ac gate voltage vs. local-oscillator drive between a non-resonant/resonant tank with a loaded Q of 14 (150 MHz frequency).

<table>
<thead>
<tr>
<th>power in (mW)</th>
<th>non-resonant gate voltage (V)</th>
<th>resonant gate voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.20</td>
<td>5.4</td>
</tr>
<tr>
<td>20</td>
<td>0.29</td>
<td>7.7</td>
</tr>
<tr>
<td>30</td>
<td>0.33</td>
<td>9.4</td>
</tr>
<tr>
<td>60</td>
<td>0.44</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Since the gate capacitance of the MOSFETs is voltage dependent, the reactance becomes dependent upon the impressed excitation voltage. To allow this condition would severely degrade the IMD performance of the mixer. However, this reactive dependence on excitation voltage can be minimized using a com-

their bias, and serious signal voltage overload results in severely degraded IMD performance. The effects of sinusoidal excitation on gate bias are easily seen in fig. 7.

building the mixer

Based on the knowledge derived from eqn. 3, low source resistance, \( R_g \), and high local oscillator excitation voltage, \( V_L \), are ideal conditions for a mixer. The Si8901, operating as the mixer switch, offers a typical on-resistance of approximately 23 ohms when excited by a gate potential of 15 volts. Using the popular 4:1 i-f output transformer to a 50-ohm preamplifier, \( R_L / r_{DS(on)} \sim 8 \), fig. 5 suggests optimum conversion efficiency with an \( R_g \) of 92 ohms. This is contradicted in eqn. 3, which shows that optimum IMD performance results with the lowest possible \( V_L \). This result is achieved by lowering \( R_g \). It now becomes clear that a performance tradeoff may be necessary. Either we seek low conversion loss, and with it a low noise figure, or aim for the highest IMD performance. Fortunately, as we seek high performance, the dynamic range will improve since a mismatched signal port has less effect upon the signal-to-noise performance than a matched signal port has upon IMD.

establishing the gate drive

Using the conventional broadband, transmission-line transformer characteristic of the diode-ring DBM requires massive local oscillator drive to effect the required gate voltage needed to satisfy eqn. 3. Earlier MOSFET commutation mixers required watts of local oscillator drive to achieve high dynamic range!2

One obvious means of obtaining a high gate voltage is to use a resonant gate drive. The voltage appearing across the resonant tank, and thus on the gates, may be calculated as

\[
V = (PQX)^{1/2}
\]

where \( P \) is the local oscillator power delivered to the resonant tank
\( Q \) is the loaded \( Q \) of the resonant tank
\( X \) is the reactance of the gate

Since the gate capacitance of the MOSFETs is voltage dependent, the reactance becomes dependent upon the impressed excitation voltage. To allow this condition would severely degrade the IMD performance of the mixer. However, this reactive dependence on excitation voltage can be minimized using a com-

fig. 5. Insertion Loss as a function of \( r_{DS} \), \( R_L \), and \( R_g \)

fig. 6. Effect of sinusoidal local-oscillator waveform on i-f linearity.

fig. 7. First- and third-quadrant I-E characteristics showing effect of gate voltage leading to large-signal overload distortion.
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Telex: 78 841

<table>
<thead>
<tr>
<th>EIMAC Cavity</th>
<th>Matching EIMAC Tube</th>
<th>Tuning Range (MHz)</th>
<th>Power Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-2200</td>
<td>4CX20.000A</td>
<td>86-108</td>
<td>30 kW</td>
</tr>
<tr>
<td>CV-2220</td>
<td>3CX1500A7</td>
<td>86-108</td>
<td>1.5 kW</td>
</tr>
<tr>
<td>CV-2225</td>
<td>4CX3500A</td>
<td>86-108</td>
<td>5 kW</td>
</tr>
<tr>
<td>CV-2240</td>
<td>3CX10,000U7</td>
<td>54-88</td>
<td>10 kW t</td>
</tr>
<tr>
<td>CV-2250</td>
<td>3CX10,000U7</td>
<td>170-227</td>
<td>10 kW t</td>
</tr>
<tr>
<td>CV-2400</td>
<td>8874</td>
<td>420-450</td>
<td>300/1250 W*</td>
</tr>
<tr>
<td>CV-2800</td>
<td>3CX400U7</td>
<td>850-970</td>
<td>225 W</td>
</tr>
<tr>
<td>CV-2810</td>
<td>3CX400U7</td>
<td>910-970</td>
<td>190 W</td>
</tr>
</tbody>
</table>

* pulsed power
† peak sync. or 2.5 kW combined in translator service
bination of gate and substrate biasing. As we saw in fig. 6, the offset gate bias helps to achieve the required 50-percent duty cycle for optimum IMD performance.

Table 2 and fig. 8 offer an interesting comparison between a resonant-gate drive with a loaded Q of 14 and conventional drive using a 50 ohm to 200 ohm (100-0-100) 4:1 transformer. The full impact of a high-voltage gate drive can be seen in fig. 9, which shows close agreement between the calculated (eqn. 3) and the measured IMD.

designing the mixer

Achieving the low signal input impedance can be easily accomplished using the Mini-Circuits T1-1T (1:1) broadband transformer. Likewise, for the i-f output, the Mini-Circuits T4-1 (4:1) does an excellent job.

The principal effort is the resonant gate drive, which necessitates an accurate knowledge of the Si8901’s total capacitive loading. The data sheet offers typically 4.4 pF. To ensure good interport isolation, symmetry is critical. If this resonant tank is driven from an asymmetrical local oscillator source (coax), an unbalanced-to-balanced transformer ensures symmetry (see complete mixer schematic shown in fig. 3).

performance of the Si8901 commutation mixer

The following tests were performed across the 2-to-30 MHz hf band.
- conversion efficiency (loss)
- two-tone, third-order intercept point
- compression level
- desensitization level
- noise figure

The conversion loss and input intercept point are plotted as a function of local oscillator drive power in fig. 10.

The 2-dB compression and desensitization levels appear to contradict what is normally expected based on the +17-dBm local oscillator drive until we are reminded that the mixer’s performance is based on gate voltage, not gate drive expressed as power. Both were measured at +30 dBm. The single-sideband noise figure was 7.95 dBm.

If the design engineer follows the concepts suggested in this note, the Siliconix Si8901 will provide the highest dynamic range of any comparable mixer currently available. Achieving a high gate voltage using a resonant drive does not label the mixer as a narrowband device. Tank tuning may be accomplished in a number of ways, such as electronic tuning using varactors. It is conceivable that the tank may be the output of an electronically tuned balanced local oscillator circuit.

references


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the IC-781
ICOM's newest transceiver

By J. Craig Clark, Jr., N1ACH, Assistant Publisher, *ham radio.*

Rumors have been flying for the past few months about a major new radio on the way from Japan. We've carefully watched the Japanese *CQ* ads first appeared in February issues of American Ham magazines. ICOM has also been showing the unit at various dealers around the country in conjunction with ICOM DAY promotions. When I found that the new ICOM IC-781 was going to be at Hamtronics in Trevose, PA, in early December, I decided to get a hands-on demonstration.

A few days later, I found myself standing in front of the store in Trevose. Though it was still pretty early, a fair crowd had already arrived and was hovering around the IC-781. After making my way through the throng and introducing myself to the Hamtronics gang and Evelyn Garrison and Mike Vincent from ICOM, I got my first look at the radio.

Let me give you an overview of the radio's unique features. While the price is rather steep, (about $7,000) one thing to remember is that an innovative radio like this has a trickle-down effect within the industry. If you look back about 20 years to the Signal One CX-7 (at the time a quantum leap in transceiver design) and compare it to today's state-of-the-art transceiver, you'll find plenty of parallels. The IC-781 will pave the way for many new features you'll want in your next radio.

The first thing you notice about the IC-781 is its 5-inch CRT display set smack dab in the middle of the radio's front panel. Other than that, it bears a striking physical resemblance to ICOM's IC-761 transceiver. The unique feature of the IC-781 is that it contains a spectrum analyzer which gives you a picture of band occupancy and relative signal strength in 100, 200, and 400-kHz windows centered on your operating frequency. As with a conventional spectrum analyzer, frequency is plotted on the horizontal axis and signal strength on the vertical.

DXers will find this to be a boon in finding pileups as they scan the bands. Big wide blips will indicate hotbeds of activity. Contesters will no longer have to search up and down the band for...
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MIRAGE NEWS

Vol. MCMLXXXVIII

Fact Sheet

February 1988

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One of the biggest problems with transistor amplifiers is thermal overload — during excessive key down operation the amplifier will shut down due to excessive transistor heat build up. MIRAGE's new heat sink uses a special manufacturing process to imbed copper in the aluminum body. Copper is 2.5 times more conductive than aluminum and ensures more rapid and even heat dissipation throughout the heat sink. By reducing the amount of heat in the amplifier, transistor life has been significantly improved. The extra margin of safety means you don't have to worry about shut down during long winded FM conversations or RTTY operation.

Morgan Hill, CA
NEW 160 WATT 2 METER AMPLIFIER

Here's a new amplifier active 2 meter operators will want! Designed with the DX'er in mind, the new B3036 amplifier gives a full 360 watts output with just 30 watts of drive power. Also includes a low noise (0.5dB) GaAs FET pre-amplifier with a helical resonator front end. Uses MIRAGE's new copper/aluminum high dissipation heat sink with built-in fans for extra protection and heat transfer. The unit measures approximately 13" x 5½" and is powered by 136 volts DC at 40 amps. Carries the MIRAGE five year warranty, one year on transistors.

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Designed to meet the challenge of the severest of weather conditions, KLM now offers a heavy duty boom for its line of HF antennas. The boom is a 3" diameter by .25" wall size piece of aluminum. Instead of swaged ends to join pieces, the heavy duty boom uses splice sections that insert into the boom. The splices are made from the same rugged aluminum as the boom and are designed to meet or exceed the most demanding Amateur requirements. Contact your KLM dealer for this special order item.

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Multiband QRV 160-10 Emergency Pack

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clear frequencies to set up a new run. Also, by looking at relative strengths of signals and finding out what areas of the world are coming in the best, you can determine if it’s better to look for new multipliers or try to run them.

The multi-function CRT displays VFO A and B frequencies, memory contents and, when connected to an external TU such as the Kantronics KAM, MFJ, or AEA PK-232, the demodulated output of CW, RTTY or other digital modes. This eliminates the need for a bulky external monitor.

But that’s not all! In addition to the CRT display features, the IC-781 also has a number of other interesting capabilities.

For example, you can listen on both VFO frequencies simultaneously (while in the same band) and vary audio balance between each. Don’t want to miss that rare DX station that’s working call zones? Tune the DX station on VFO B, turn the audio balance up enough so you can hear and keep track of his operation, tune VFO A to an open spot and call CO. When the DX station gets to your call area, switch VFOs and call. Or, when you are working a split frequency pileup, adjust the audio balance between VFOs so you can keep track of both your transmit and receive frequencies. Too many stations calling on your transmit frequency? Slide up 500 Hz without losing track of the DX station and call again. It’s that easy.

Another innovation is the twin passband tuning capability. You can tune the second and third IF separately for double passband tuning or together as an IF shift. Sometimes you want that extra ability to reduce an interfering signal. The double passband control will give you this.

Recognizing that in many cases 90 to 110 watts power output is not enough to fully drive many of the amplifiers now available, ICOM has increased the power output of the IC-781 to a generous 150 watts level. This should be more than enough to drive grounded grid amplifiers to full legal output or provide that extra bit of signal when running “barefoot”.

The IC-781 also comes with: built-in switching power supply, automatic “one-button” antenna tuner, keyboard frequency entry control, dual noise blanker with monolithic crystal filter, 99 tunable memories, wide and narrow filters, and an internal iambic keyer at no additional cost.

As you can see by looking at the photos, the IC-781 is a pretty complete radio.
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optimizing gain on Yagi antennas

Examination of "short" boom Yagi reveals surprising results.

In the recent past, Yagi antenna construction was as much folklore, superstition, and magic as it was science and engineering. For example, the guidelines for constructing a Yagi antenna provided in the ARRL's 1980 Antenna Handbook include a general table of ranges for "optimum" element spacing, but not a formula for determining optimum element lengths. Would an antenna built according to this data really be "optimum?"

Computer modeling of Yagi antennas provides a means of answering this question by allowing us to examine the effects of element length and spacing perturbation and by providing an efficient and reproducible means of calculating gain and pattern. Even with some major simplifying assumptions about element interactions and element self-impedance, the result of Yagi modeling predicts the results from the antenna test range. Two previous papers examined the change in forward gain with different taper regimens — i.e., all directors the same length, all directors getting shorter towards the front, all directors longer towards the front. Although a taper regimen may offer a slight advantage, the difference is almost vanishingly small. For example, maximum gain on a 3.44-wavelength boom Yagi with no director taper was 15.601 dBi, and the maximum gain with an "optimum" director taper was 15.618 dBi. However, these previous studies imposed a fixed geometric relationship between the directors, although the only rationale for this is aesthetics. In his thesis work, Dr. Chen found that Yagi antennas maximized for forward gain smoothly converged to a single unique solution and, from his examples, director lengths had no apparent geometric relationship. Thus, the question of maximizing gain by changing director size deserves a second look without the constraint of a fixed physical relationship between director lengths.

The purpose of this article is to examine Yagi gain performance under certain constraints:

- Maximum boom length will be limited to one wavelength, which is about the longest practical boom on 15, 20 or 40 meters.
- Antennas will be optimized for maximum gain. By concentrating on antenna gain, front-to-back ratio and bandwidth are not considered. While both are important, both generally take away from forward gain. Our primary focus is: what is the maximum Yagi gain for a given boom length, and how much better is the optimized gain from where we started?

procedure

Antennas will be modeled in free space using the assumptions presented in the appendix. The basic antenna design is initially estimated using the general principles outlined in the ARRL's Antenna Handbook, with equal spacing between the elements. Initial parameters are:

- Element diameter: 0.001 wavelength (1 inch on 20 meters)
- Reflector length: 0.51 wavelength
- Director lengths: 0.45 wavelength

The reflector's length will be increased by 0.0025 wavelength; the gain will again be calculated. If the forward gain improves by more than 0.01 dB, then that element will be incremented again in the same direction. If forward gain does not improve, the element will be shortened until the gain starts falling off. Once the reflector is optimized for forward gain, the same procedure is applied to the directors in order, and then back to the reflector. This iteration is continued until no further gain improvement is noted for a complete cycle through all parasitic elements. Once the antenna is optimized for forward gain using element perturbation, this same procedure is applied for element spacings with the first and last element fixed at the ends of the boom. Table 1 presents the starting and final values after forward gain optimization for some representative examples. After optimizing an antenna with equal element spacing, the same procedure is done for some antennas with unequal spacing.

For a given boom length and element spacing, the element lengths were found to converge smoothly to the same final values and were independent of starting lengths. Element and boom lengths in the tables are presented in terms of wavelength, but for figs.

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configuration that increased to 7.2 to 8.6 with optimization. A gain increase of 0.15 dB over equal spacing was found with close spacing of the driven-reflector in the three element configuration. On longer booms (.34, .43, .52, .60 and .68 wavelength, 24, 30, 36, 42 and 48 feet on 20 meters), configurations had between 8.0-9.1 dBi forward gain before and 9.1-9.6 dBi after optimization. A 4 element configuration on a .34 wavelength boom was about 0.2 dB better than a 3 element configuration.

Large antennas on booms of 0.77, 0.86, 0.95 and 1.0 wavelength (54, 60, 66 and 72 feet on 20 meters) had 10.1-10.5 dBi. Following optimization these antennas had 10.5-10.8 dBi.

Overall, the improvement in forward gain from the starting values was 0.7 (range: 0.3 to 1.53) dB, averaged over all the antennas, and usually came at the expense of front-to-back discrimination. In no case did the optimized antenna show any particular pattern in director taper — i.e., all elements getting shorter or longer.

Once an antenna is optimized for forward gain using element perturbation, changing the element spacing resulted in only minor forward gain improvement. The only exception was with wide spaced antennas (i.e. > 0.2 wavelengths) which work better with shorter element spacing between the reflector and driven elements.

In general, gain optimized antennas had reflectors which were rather short (about 0.49 wavelength or \(+j\) 30 ohms) and at least one director which was rather long (0.45-0.46 wavelength or \(-j\) 10 ohms). Since some parasitic elements are close to resonance, the optimized antennas would likely have a very limited bandwidth, and not adequately cover the CW and phone portions of the bands.

For a given boom length, the maximum gain figure was independent of the number of elements or spacing, with a slight edge to antennas with a short spacing from driven element to reflector (about 0.2 dB). Of particular interest is the relationship between maximum forward gain and boom length (fig. 1). The curve is not smooth, and shows a pronounced plateau after the 24-foot boom on 20 meters (0.35 wavelength) before again increasing with a 48-54-foot (0.76 wavelength) boom.

Discussion
These results suggest two conclusions:

- Yagi antenna gain is basically only a function of boom length. However, the increase in gain is not smooth for boom lengths between 24 and 70 feet on 20 meters. Increasing the boom length from 24 to 48 feet increases the maximum gain by only 0.5 dB, while

1 and 2, the boom length is translated to a 20-meter antenna in order to provide a clearer sense of physical size.

Results
Two- and three-element antennas on a short boom (0.17 and 0.258 wavelength, 12 and 18 feet on 20 meters) showed 6.8- to 6.9-dBi gain in the initial con-
Table 1. Element length and spacing, forward gain and front-to-back ratio (at the end of the horizon) for two-eight elements with boom lengths between 0.172 to 1 wavelength (12 and 70 feet, respectively, on 20 meters). Row S shows the starting element length (wavelength) with a diameter of 0.0005 wavelength. The position of the element from the reflector end of the boom is given in parenthesis. R is the reflector, De is the driven element, D1 – D6 are the first through sixth directors.

<table>
<thead>
<tr>
<th>element length (boom position)</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>gain (dB)</th>
<th>F/B (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 0.510(0)</td>
<td>0.470(1.17)</td>
<td>0.450(0.35)</td>
<td>0.450(0.35)</td>
<td>6.67</td>
<td>9.9</td>
</tr>
<tr>
<td>O 0.490(0)</td>
<td>0.470(1.17)</td>
<td>0.450(0.35)</td>
<td>0.450(0.35)</td>
<td>7.23</td>
<td>7.2</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.11)</td>
<td>0.450(0.22)</td>
<td>0.450(0.35)</td>
<td>8.07</td>
<td>34.7</td>
</tr>
<tr>
<td>O 0.492(0)</td>
<td>0.479(0.15)</td>
<td>0.482(0.35)</td>
<td>0.450(0.35)</td>
<td>9.11</td>
<td>4.6</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.11)</td>
<td>0.450(0.22)</td>
<td>0.450(0.35)</td>
<td>8.43</td>
<td>16.9</td>
</tr>
<tr>
<td>O 0.496(0)</td>
<td>0.470(0.10)</td>
<td>0.442(0.25)</td>
<td>0.477(0.35)</td>
<td>9.32</td>
<td>5.5</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.17)</td>
<td>0.450(0.34)</td>
<td>0.450(0.53)</td>
<td>9.86</td>
<td>10.0</td>
</tr>
<tr>
<td>O 0.490(0)</td>
<td>0.470(0.15)</td>
<td>0.447(0.36)</td>
<td>0.460(0.52)</td>
<td>9.35</td>
<td>6.3</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.15)</td>
<td>0.450(0.30)</td>
<td>0.450(0.45)</td>
<td>9.12</td>
<td>10.1</td>
</tr>
<tr>
<td>O 0.490(0)</td>
<td>0.470(0.15)</td>
<td>0.445(0.32)</td>
<td>0.472(0.44)</td>
<td>9.42</td>
<td>8.5</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.17)</td>
<td>0.450(0.35)</td>
<td>0.450(0.52)</td>
<td>10.31</td>
<td>11.2</td>
</tr>
<tr>
<td>O 0.492(0)</td>
<td>0.470(0.15)</td>
<td>0.427(0.34)</td>
<td>0.455(0.53)</td>
<td>10.5</td>
<td>9.8</td>
</tr>
<tr>
<td>S 0.500(0)</td>
<td>0.470(0.15)</td>
<td>0.450(0.30)</td>
<td>0.450(0.44)</td>
<td>10.67</td>
<td>10</td>
</tr>
<tr>
<td>O 0.517(0)</td>
<td>0.470(0.15)</td>
<td>0.467(0.30)</td>
<td>0.450(0.59)</td>
<td>10.97</td>
<td>13</td>
</tr>
</tbody>
</table>

increasing the boom length by another 12 feet (to 60 feet) offers a 1-dB improvement.

If one starts with reasonable element lengths, the average improvement in gain that can be expected is about 0.7 dB.

In other papers, Yagi gain was generally considered to be a smooth function of boom length. Bill Myers fit the NBS test range results to a curve and found good agreement for the function: Gain (dBi) = 3 In (boom length) + 12 dBi. However, this was fit with data from boom lengths of 0.4 to 4.2 wavelength, and only two points at one wavelength or less. An examination of the calculated gains from a previous article suggests a conclusion similar to the one drawn here (fig. 2, line 2). A datum point for this figure was the peak gain numbers from all of the frequency points and all the element configurations for a given boom length presented in references 8 and 9. Keep in mind that these were not gain optimized antennas. Here again, forward gain was not a smooth function of boom length, but also showed a plateau region above 0.3 wavelength (24-foot boom on 20 meters). Although the plateau points don’t correspond exactly to the lengths found in this paper, the phenomenon of nearly doubling boom length for 0.5 dB or less increase in gain is visible.

If one accepts this staircase phenomenon in forward gain, one would conclude that the ideal place to sit is at the edge of the step. From the computer results presented here, a good choice would be an optimally tuned four-element Yagi on a 24-foot boom for 20 meters. If you go to the effort of doubling the boom length to 48 feet, which probably requires a larger rotor, the forward gain may stay within 0.5 dB of the original antenna. Even if the boom length is expanded to 60 feet, the gain increase may only be 1.5 dB over the initial antenna. Is it worth the worry when the wind picks up?

The rather small average difference in forward gain between the initial and optimized antennas is surprising. The comments of Jim Lawson, W2PV, seem to be accurate and in order: “Yagi antennas ‘want’ to work.” The gain of non-optimized antennas is usually within 1 dB or so of the maximum possible gain. This frees the designer to optimize for other factors such as pattern nulls or average front-to-back without major worry that the forward gain will be compromised. Furthermore, one should not expect great increases in forward gain through fine tuning of the antenna. This may limit motivation for running up and down the tower, and performing hundreds of “This is antenna one, this is antenna two...” tests. Similarly, there is no magic about any particular antenna configuration. Thus, a 20 meter Yagi on a 24 foot boom should work the same (within a dB) whether it is homemade or from a commercial manufacturer.

In attempting to build actual antennas from data such as these, several factors must be kept in mind.
Although computer folks, myself included, tend to express gain to the hundredth or thousandth dB, the simplifying assumptions probably invalidate such accuracy. For instance, other investigators have assumed a real value for the self-impedance of 73 ohms, while in reality, self-impedance varies between 50 and 100 ohms, depending on element length and diameter. Therefore, some of the terms in the impedance matrix are perhaps 20 percent in error. And an assumption that mutual impedance (coupling) between elements is independent of element length is probably only 90 percent accurate — shorter elements are less coupled. Nevertheless, despite these assumptions, the computer results show good correspondence to test range results, and many fine working antennas have been based on computer designs. A critical factor to keep in mind in implementing computer design data is constructing the same type element that was modeled; this is affected not only by element length, but also element diameter and physical taper. Two other papers provide an excellent discussion of this point.

**conclusion**

Short antennas (with a 0.35-wavelength boom) can work very well, and it may not be cost effective to increase the boom size unless one goes almost two and a half to three times longer. Changing element lengths or element positions may provide a gain increase of about 1 dB.

**appendix**

This appendix provides the assumptions used for modeling the Yagi antennas, including how the mutual impedance matrix and gain were calculated. A more complete description of the general methodology is given elsewhere.

The following assumptions and methodology were employed:

1. The mutual impedance between elements is assumed to be independent of element length and to be equal to published values for half-wave elements. This assumption was also used by others and obviates the need to calculate mutual impedance for each antenna configuration, thereby greatly reducing computational time.

2. The self-impedance of an element is computed using Tai’s formula, which estimates the real and imaginary self-impedance terms based on element length and element diameter:

\[
Z_{\text{self}} = \left| 122.65 - 204.1 (k \xi) + 110 (k \xi)^2 \right| - j 120 \left| n \left( \frac{2 \xi}{a} - 1 \right) \cot (k \xi) \right| - 162.5 + 140 (k \xi) - 40 (k \xi)^2
\]

where \( \xi \) is the element length, \( k \xi \) is 2 pi/wavelength, and \( a \) is the diameter.

3. The impedance matrix is inverted and multiplied by the driving voltage matrix to give the element current distribution. The element currents are multiplied by the array factor for dipole elements to give the E-field at a given value of theta and phi (spherical coordinates). The total radiated field is calculated by integrating theta and phi over a sphere and the gain in any direction is computed as the field ratio of the power in that direction divided by the average power flowing through the sphere. While this is theoretically equivalent to calculating the power in the forward direction and comparing to the input power at the driven element, it is probably more accurate, since it is independent of uncertainties in driving impedance.

4. Because all calculations are done in free space, ground effects are neglected. The assumption is that the effect of the ground, which is to reinforce or cancel the radiated field, does not play a significant role in determining the current distribution.

Some reviewers of this manuscript were incredulous about the conclusion that forward gain did not increase smoothly with boom length and suggested that perhaps my underlying assumptions biased the results. Subsequently, I have performed the same optimization procedure using a version of MININEC with 20 match points per element. MININEC calculates all self and mutual impedances between element segments and thus does not use some of the assumptions I presented. Although the optimized element lengths were somewhat different than what I showed in table 1, the relationship of boom length to forward gain and the amount of improvement noted with gain optimization was identical. (See fig. 2, lines 1, 3.)

**references**

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Why are so few hams building electronic gear these days? To find out I conducted a survey among my ham friends. Three major reasons are:

- Lack of parts and difficulty in finding the necessary materials at reasonable prices.
- Choosing the wrong projects. Some pick projects of no use to their ham operations or that are too difficult for them to complete.
- The challenge of metal work can be overwhelming.

The parts problem

Inexpensive parts are readily available from many sources. Here are some possibilities:

- Local radio clubs often hold sales and auctions. Large, heavy World War II equipment (often called boat anchors) usually sells at give-away prices. Strip down for usable parts and hardware. Keep all screws, nuts, spacers, and small parts such as capacitors and resistors. Your junk box will soon overflow with building material.
- Garage and silent-key sales often yield worthwhile items. Look for wire, solder, tools, coax fittings, connectors, etc. If you don't have an immediate need, buy parts and store them for future use.
- Hamfests. Watch for notices in ham publications. The flea market is usually the main attraction; the variety of material is unbelievable. Where else can you buy a Weston meter for a buck? Testing your bargaining skills is fun.
- Electronic surplus houses. These are scattered across the country, and frequently advertise in the yellow pages of the local phone book. Better companies often publish catalogs.
- Junk yards. Some of my best buys were made at junk yards where electronic material occasionally shows up as a byproduct and the seller doesn't know its value. I recently purchased some excellent coaxial cable at ten cents a foot.
- Ham friends. Some of your acquaintances may have a basement, garage, or an attic full of items collected in the heyday of World War II surplus sales.
- On-the-air swap meets can be an excellent source of cheap parts. I have contacted many hams on the air to buy hard-to-get items. You must be flexible in your selection; sensible substitutions come from experience.

Selecting the right project

Keep your first project simple. It's easy to get discouraged if your initial attempt is too difficult. As you finish one project, look for something more complicated to test your abilities. I started building items such as field strength meters, moved on to antenna tuners, and finally to a linear amplifier. Build an item you will use in your ham operations. You'll give your confidence a boost if you build something and use it.

Preliminary design

The foundation of any electronic project is the panel, chassis and, cabinet. Do your homework on circuit design and determine its size before gathering materials.

When you have all the necessary parts, decide on their proper placement. Look at handbook illustrations and photos to see how the experts do it. Juggle the parts into a configuration that meets your project's requirements. For example, short rf leads are important. Keep the coils spaced from metal shields by a distance at least one half their (coil) diameter. The rf switches must be close to the coils to maintain short lead length. Allow plenty of space around high-voltage components to avoid flashovers.

Don't design in layers that will be hard to wire initially; it may be difficult to repair or replace components later.

Metal fabrication

Most hams dislike metal work either because they don't have the proper tools or don't know how to use them. This situation has an easy solution.

Cabinet and chassis dimensions are determined when your design and parts placement are frozen. Now start looking for sources of sheet aluminum. It's the only material easily worked and electrically excellent. I find aluminum at salvage yards, surplus houses, and flea markets. Prices average $1.25 per pound. Buy 6061T-6 alloy for panels or pieces that don't need bending. Material 1/8 inch thick is needed; it's stiff and machines cleanly. Choose bendable material for the chassis and outer cabinet. Test for flexibility by bending a small corner with a pair of pliers. It should

By Paul A. Johnson, W7KBE, 10817 Brookside Drive, Sun City, Arizona 85351

26 March 1988
Greenlee punches are useful for making holes ranging from 1/2 to 1-1/2 inches in diameter. Aluminum angle, 1/4-inch threaded rod and nuts, 6-32 machine screws and nuts, and no. 6 drive screws are needed and can be found at well-stocked hardware stores.

bending aluminum

You'll need to bend the aluminum for the chassis and cabinets, something that's difficult to do with regular home tools. Take the pieces that need bending to a local sheet metal shop. Let the metal worker figure the dimensions as he knows the allowances that have to be made for proper fitting. Sometimes you can avoid making bends by using angle aluminum.

tools to use

You can cut aluminum easily with hack, sabre, circular, and hole saws or with a fly cutter. Cut meter holes with a hole saw or fly cutter (which must be used in a drill press at its lowest speed). Fly cutters can be dangerous; use cutting lubricants like kerosene or paraffin and smooth ragged edges with a file. Clamp the panel to the table, cut halfway through, then turn the panel over to finish the job. Greenlee punches are useful for making holes ranging from 1/2 to 1-1/2 inches in diameter.

finishing the metal work

After drilling the holes, assemble the pieces to make sure everything fits. Now disassemble and clean each surface with sandpaper (100 grit). Remove all burrs and scrub down the metal with an abrasive cleanser; now you're ready to paint. I paint only the front panel and outer shell; try making the panel one color and the outer shell another as contrasting colors enhance the finished product

Figure 1 shows the skeleton frame of an assembly designed to house a linear amplifier. Note the simple construction. The front and back panels are the same size, and held together with four 1/4-inch threaded rods. To assure perfect alignment between front and back panels, clamp them together and drill holes for the 1/4-inch threaded rod through both. The meter shield has only one 90 degree bend. The side rails, chassis, and outer shell covers all have two bends. With the outer shell in place, all the necessary shielding is complete.

The chassis is open for ease of assembly. When all parts are in place, wiring is easy. Nothing is buried. Coils, switches, and capacitors are placed for efficient operation at radio frequencies. Figure 2 shows that there is no layering of parts. This makes future repairs, changes, or parts replacement easy.

Figure 3 shows a completed 1-kW linear amplifier. The outer shell is held to the side rails with no. 6 sheet metal screws. The front of the cabinet extends beyond the front panel to give a shadow box effect similar to many commercial cabinets.

This open frame construction can be still be used if you find a commercial cabinet that fits your needs. Figure 4 shows an antenna tuner for 40, 80, and 160 meters designed for open wire line. The sliding switch and the coils are homemade. The assembly in Fig. 4 was easy to wire and slides into a commercial cabinet.
the appearance. Epoxy metal spray paint does a good job.

the final touch

Reassemble and wire all components. You need to maintain excellent contact between parts and sheet metal. Don’t skimp on the number of screws; rf grounds are very important.

fig. 3. Here’s the amplifier buttoned up and ready for action. Plenty of meters are available to monitor all circuitry. A symmetrical layout of the front panel adds to the appearance. Notice the use of surplus dial counters and meters.

I have built many of these cabinets for my friends and myself. The designs evolved over years of trying to simplify construction of homebrewed equipment. I think the finished product is very functional. Why not give it a try?


Ham Radio
automatically switched half-octave filters: part 2

Modular approach facilitates construction, improves performance

In part one, we discussed the low-pass and bandpass requirements for multi-octave transmitters and receivers. They differ considerably from the ones needed for narrowband applications like those in Amateur equipment with 500-kHz band coverage. We found that the best way to use filters in a multi-octave transmitter application with stringent attenuation and ripple characteristics is to select contiguous half-octave networks that will attenuate second-order and higher harmonic products while maintaining flat bandpass characteristics (fig. 1).

We discussed the practical limitations of filter design and the tradeoffs in linear amplifier design necessary to reduce the complexity of the filters, presented an ideal filter model, and discussed how some practical filter approximations can satisfy stringent requirements better than others. Based on this knowledge, we selected the Cauer (elliptical) filter for our application, and designed bandpass and low-pass networks for a full coverage transceiver. In part 2, we will implement the low-pass filters from table 3 of part 1 in the transceiver environment. This requires additional design in the areas of rf switching and digital decoding that will have to work with the filter networks, the control system of the transceiver, and the mechanical design.

system implementation

Because the low-pass networks must withstand high power (and high VSWR), they need to be implemented with relatively large inductors and capacitors, which will take up space in the compact transceiver.

fig. 1. Breadboarding the automatic filters for the WB3JZ0 transceiver.

By contrast, the modular packaging of the transceiver dictates the use of small pc boards containing sensitive driving circuits and arrays of rf power relays for switching in the proper networks at the right time. This combination of rf and digital circuits could be cumbersome if not properly designed and implemented, even though we planned the networks with a minimum number of poles.

A special approach to packaging was adopted in the WB3JZ0 transceiver. To keep the digital circuits away from the rf, the filter networks are packaged in separate plug-in assemblies, each containing four filters (fig. 2A). The assemblies plug into pc boards containing all the digital circuitry and switching. Stainless steel containers were constructed with Teflon™ standoffs to give mechanical support to the inductors and capacitors. In addition, a set of precision-guided RCA connectors were built into the containers for quick connect/disconnect of all filters from the pc boards. This construction proved effective in preventing the

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fig. 2A. Implementing the filter banks in the WB3JZO transceiver. Stainless steel containers with built-in Teflon™ stand-offs and precision guided RCA connectors allow off-board access to the filters for tuning. This packaging keeps rf out of the digital circuits.

fig. 2B. Filter assemblies are easily inserted into the pc boards which in turn plug into the transceiver.

fig. 3. View of the amplifier assemblies and associated filter banks.

digital testing of the networks and their switching. Each bank of filters can be plugged or unplugged from the pc boards (fig. 2B). Two board assemblies are required for the eight low-pass filters. Only one board is needed to accommodate the bandpass filter bank, since the size of the parts for these filters permits miniaturization.

Many other design goals were considered. An opto-encoded digital count up/down circuit on the digital interface command board (DBIC) at the front of the transceiver provides decoding for all filter banks, and works in conjunction with two other interface boards. The frequency word logic board (FWLWB) lets the operator dial up any frequency from the transceiver’s front panel and the frequency mode display board (FMDB) serves as digital display feedback. The high-gain (39 dB) linear amplifier chain and the low-pass filter banks are shown in fig. 3.

The system is implemented modularly and connected via ribbon cables and motherboard layout to decode and communicate information to the proper automatically selected filters. The rf paths are joined by RG-174/U and RG-58/U coaxial cables, depending on rf power requirements. Digital information is transmitted to the synthesizer as corrected by the i-f value and CW shift. Several other functions were incorporated: power-up memory for the “mode” mechanism, ensuring that the transceiver always starts up in upper sideband; alpha-numeric display circuits with electronic band edge stops at 2 and 30 MHz, to prevent operation outside the range; various sequencing and delay circuits that work in conjunction with the synthesizer; and AGC command functions, thumbwheel encoding circuits, and a multiple-tone alert system working in the receiver’s audio section. Figure 4A shows all significant digital assemblies and the filter banks prior to final transceiver packaging; figs. 4B and 4C show their incorporation in the transceiver.

building the filters

Next, we will see how the low-pass filters from table 3 of part 1 were constructed. First, precision inductors were devised for all values from the table. We used commercial Micrometals™ T-68 toroid cores — red mix No. 2 for the lower frequency banks and yellow mix No. 6 for the higher frequencies. The number of turns (N2) was calculated using the equations listed in table 1. The final inductance adjustments were made with the setup shown in fig. 5.

By placing a precision silver mica capacitor of known value across each of the inductors and using a grid dip meter and digital frequency counter to measure the resonance of the circuit, the value of L was calculated with the equations shown in table 2. The counter measured the frequency of the grid dip meter’s oscillator at the precise resonance point. The
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RS-M SERIES

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VS-M AND VRM-M SERIES

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RS-S SERIES

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Table 1. Equation used to calculate the number of turns ($N_2$).

\[
\frac{L_1}{|N_1|^2} = \frac{L_2}{|N_2|^2} \quad \text{Eqn. 1}
\]

\[L_1|N_2|^2 = L_2|N_1|^2 \quad \text{Eqn. 2}
\]

\[|N_2|^2 = \frac{L_2|N_1|^2}{L_1} \quad \text{Eqn. 3}
\]

\[N_2 = \sqrt{\frac{L_2|N_1|^2}{L_1}} \quad \text{Eqn. 4}
\]

Where:

- $N_2$ = Required number of turns
- $L_1$ = Known inductance per 100 turns*
- $L_2$ = Known required inductance
- $N_1$ = 100

*Values of $L_1$ from tables
- T68-2 = 55 $\mu$H
- T68-6 = 47 $\mu$H

Table 2. Equation used to calculate the value of $L$.

\[L = \frac{25330}{(F^2 C)} \quad \text{Eqn. 5}
\]

\[C = \frac{25330}{(F^2 L)} \quad \text{Eqn. 6}
\]

Example: If $C = 107.6$, $L = 3.40$ $\mu$H
To resonate at 8.316 MHz
(from filter no. 1, Table 3 (from part 1)).

Numbers were entered into a TI-59 calculator programmed to solve for $L$ or $C$ according to the equations. This semiautomated process allowed quick, consistent, error-free calculations, making measurements for all the inductors easy. The setup worked well for all cases. Adjustments were made to the coils by pushing or spreading the windings a bit. The same procedure was used to obtain practical combinations of capacitor values approaching the theoretical values prescribed in Table 3 of part 1. In this case, the equation was solved for $C$ rather than $L$ (Table 2). The parts were then soldered into the containers, using RCA connectors and Teflon standoffs as mechanical supports. The filters were then tuned for theoretical peaks with a Collins R-392 receiver used as a spectrum analyzer. We later used an HP-8754 network analyzer to complete the job.

Figure 6 shows the composite frequency response of the finished low-pass filters as plotted with the

---

**Figure 4.** (A) View of significant assemblies associated with the implementation of the filters. Shown are all filter banks and the digital interface command board (DBIC). (B) and (C) Views of all digital boards and filter assemblies as packaged in the transceiver. In addition to the boards and visible behind the front panel are the frequency word logic board (FWLB) and the frequency mode display board (FMDB). All boards are interconnected via continuous ribbon cables equipped with press-on connectors.
receiver's i-f section. The 75451 is an integrated circuit containing two drivers and associated TTL logic. Two of these were used per filter board (fig. 8). Reverse-biased silicon diodes on the coils eliminated voltage transients that occur when current is interrupted.

The rf relays were standard parts chosen for their reliability and low cost (evidenced by their use in commercial maritime transceivers). Small Teledyne rf relays were used for the bandpass bank. The design lets only one filter be switched in at any given time, eliminating possible interaction between the selected filter and adjacent devices. During selection, all other filters are shorted to ground at the input and output; this is done by taking advantage of the natural resting position of

---

**communication and decoding mechanism**

The schematic diagram of the low-pass assemblies, and their switching mechanism, are shown in fig. 8A. **Figure 8B** shows the implementation of the bandpass banks with their corresponding switching. Some of the functions included here are filter switching with associated driving circuits, transmit/receive (T/R) switching, and the transmitter gain control (TGC) sensory circuit. Next, we will discuss the communication and decoding mechanism.

We decided early in the design that digital communications in the transceiver would be performed with parallel low-true TTL levels for good noise immunity in the presence of an rf field. This meant that the TTL lines would be terminated on the destination boards with 75451 line drivers, normally used in computer communications hardware. These devices deliver up to 400 milliamperes of current at 5 volts and can drive relays directly. They have been used throughout the system, in the control circuits, as relay drivers for all filter boards, and as power switches for muting the

![fig. 5. Setup used to speed up the inductance measurement process. The toroidal coil under test was paralleled by a known precision silver mica capacitor. The exact frequency of the circuit was read with a digital counter which measured the frequency of rf generated by the grid dip meter at resonance. All numbers were inputted to the TI-59 programmable calculator which resolved the equation for L or C.](image)

![fig. 6. Actual frequency response plot of all the low-pass filters was obtained with the HP-8756 network analyzer. The response curves show compliance with design goal specifications from table 1 (from part 1).](image)

![fig. 7. Typical worst-case spectrum analyzer test shows that harmonics are at least 50 dB below the carrier. Filter No. 4 was used in this example. Similar results are obtained with the other low-pass filters.](image)
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fig. 8A. Schematic diagram of the switching mechanism for the low-pass assemblies.
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*6 CTM articles; Ham Radio 10 articles; QST 5 articles; 73 4 articles; CTM 26 articles for the other ham magazines.
the relay arms. We observed no stray effects between the active filter networks and adjacent coils, despite the compact packaging. Ferrite beads were used in all relay driving lines to prevent rf from getting into the dc switching circuits. Finally, all power lines were bypassed with decoupling capacitors and rf chokes and the finished product worked smoothly.

digital intelligence

The decoding for selecting the appropriate filter networks was designed into the digital interface command board (fig. 9). When power is first applied, all logic circuits are reset via the built-in power-on strobe circuits as shown. This mutes the receiver and transmitter circuits until the synthesizer locks up on the frequency indicated by the thumbwheel switch and the dot-matrix LED display. Within a few milliseconds a short tone burst, audible through the audio amplifier of the transceiver, signals transceiver readiness. The entire transceiver then is set to the frequency indicated by the thumbwheel switch, which also controls the filter selection. The half-octave filters are automatically selected by the BCD-to-decimal decoder, which in turn activates one of the eight lines going to the filter banks (fig. 9). In addition, parallel digital data intended for the display is modified by the amount of i-f frequency before being sent to the synthesizer.

final considerations

Some additional, but unrelated, circuits are shown in fig. 9. In the WB3JZO transceiver, mode selection is made automatically at power-up and is initially in the upper sideband condition. It is controlled with a push-push sequencer button located in the front of the transceiver. Selection is indicated by a large LED display, visible through the front panel, programmed to show the letters U, L, or variations of the letter C for different CW bandwidths. Similar circuits control the AGC characteristics of the receiver, and several other functions. The frequency display shows the frequency of the thumbwheel switch (which acts as a 280,000-position band switch) as soon as power is applied. The operator can then take over the frequency control manually via the optical interrupter of the transceiver over a 10-kHz range. Split operation is activated by the memory switch (fig. 9).

When the operator sets the thumbwheel switch to the chosen frequency, the 7430 NAND gate IC detects any large frequency change and resets all circuits. This mutes the transceiver for a few milliseconds until there is lock-up and the MC-4024 generates a short sequence of tones indicating that the change has been made. Any out-of-band (i.e., outside the range of 2 to 30 MHz) condition disables transmitting and receiving circuits generating a set of aural and visual alarms (audio tones and all decimal points are lit on the alphanumeric display).

conclusion

This paper details a procedure for defining and
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fig. 9. Partial schematic diagram of the transceiver’s digital control (DBIC) used for half-octave filter selection.
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implementing automatic switched half-octave filters. The key to this method is to design the electrical filters with a minimum number of elements, while maintaining stringent electrical and mechanical requirements over a wide frequency range.

The resulting architecture is modular in that it preserves the plug-in board approach in a high-power rf environment and allows for proper digital interfacing to automate the system.

Although this project is dedicated to hf communications and particularly to linear amplifier harmonic suppression, there are many opportunities for using similar systems in other signal processing tasks. The authors would like to hear from anyone who has found new or novel applications for this concept.

acknowledgments

We would like to acknowledge Gary Dublin, N0BAB, for his help in performing the network and spectrum analyzer tests needed for the development of the WB3JZO transceiver; and Mike Stapp, KA0TQY, and Marc Denis, KD0QO, for carefully reviewing the material.

bibliography

As the techniques used by the average Amateur Radio operator become more sophisticated, the need for precise frequency control becomes more important. Satellite communications, digital data links, coherent CW operation, and even the everyday business of saying “QSY to 14259.0” all place increasing demands on our ability to accurately measure frequency. WWV and WWVH have been used for years to calibrate equipment by audibly comparing transmitted signals against the receiver’s internal reference oscillator for zero beat. This is still the most convenient method. However, for greater calibration accuracy, use station WWVB which transmits on 60 kHz.

WWVB broadcasts a highly stable reference signal in the Very Low Frequency (VLF) band and, despite its relatively low power, is receivable nationwide. Its signal is a continuous carrier modulated by decreasing output power 10 dB on the second for varying pulse widths. In this way, time, date, and error information are sent in binary format without disturbing the phase coherence of the reference signal. None of this information is decodable using standard audio detection techniques.

In recent years there have been a number of articles dealing with reception at VLF. Most employ conversion circuits which work fine for a-m, CW, and RTTY but are useless for reference work. The following circuit overcomes this limitation by using a synchronous detection scheme, which when used in conjunction with an oscilloscope, gives a convenient visual readout of frequency error.

The rf signal from the antenna is amplified without conversion using moderate selectivity and after conditioning is fed to the vertical channel of an oscilloscope. If the horizontal sweep time is then set to display about two cycles at 60 kHz (5 microseconds per cm on my scope), and the sweep is triggered by an oscillator at 60 kHz or any submultiple frequency (i.e. 60 kHz/n; where n = 1, 2, 3, etc.) the rf signal can be directly viewed. The modulation appears as amplitude level shifts on the screen, and the frequency error of the oscillator is displayed as a phase drift. Rightward drift means the frequency is high and leftward drift means it is low. The rate of error can be exactly calculated from the following formula:

\[ \text{error in parts per million} = \frac{16.7}{T} \]

where T is the time in seconds for one full sine wave to drift past a reference point on the screen. (See fig. 1.) This creates a visual converter of very high Q. The screen’s phosphorus persistence provides selectivity and the difference signal is detected as drift, easily measured in both direction and level. The result is an accurate method of frequency standard calibration at minimal cost.

using an existing oscillator

In most situations, one oscillator is established as the reference source. It can be used as a 100-kHz band marker, the master oscillator of a phase-locked loop scheme, or as the standard oscillator in a frequency counter. This reference oscillator should be calibrated by phase comparison to WWVB.

To properly use this circuit for calibration, it is necessary that the oscillator signal be brought out of your existing equipment and be processed so that a suitable submultiple frequency is available. Do some individual planning before beginning construction. Digital division is usually necessary as the oscillator frequency will be higher than 60 kHz. Most equipment has internal dividers so the subfrequency you need may already be available. Make sure that this source is not so heavily loaded by the interface circuit that stability is affected.

Suitable frequencies meet the following requirement:

\[ \text{frequency (Hz)} = \frac{60000}{n} \]

where \( n = 1, 2, 3, \ldots \text{etc.} \)

By John A. Cowan, W4ZPS, 303 Kingston Highway 293 NW, Cartersville, Georgia 30120
A 100-kHz oscillator need only be divided by 10 since the resulting 10 kHz is a suitable submultiple \( (n = 6) \). A 1, 2, 3, or 6-MHz signal could be divided by 100 as 10, 20, 30, and 60 kHz also work \( (n = 6, 3, 2, 1) \). Oscillators at 4, 5, and 10 MHz must be divided by 1000. Division by 1000 works for all the above frequencies because further division of a suitable frequency always gives another. The only drawback in using higher than minimum division ratios is that fewer sweeps per second mean a dimmer display. Some frequencies are selected for use in binary schemes and will need division by binary counters. Rarely does a frequency require complex divide-by-n circuitry.

**crystal oscillators aren’t perfect**

There’s no such thing as long term stability in crystal oscillators. Even the best commercial circuits drift as the crystals age. The best that can be hoped for is to minimize short term drift from voltage changes, loading, and ambient temperature variations. Once tuned to frequency, these oscillators drift slowly and at a constant rate. Eventually, however, the cumulative effect of crystal aging will leave the frequency far from its mark. These are the times when this circuit and WWVB come to the rescue.

**antenna considerations**

Many antenna designs are suitable for use at 60 kHz. Loops, top-loaded verticals, and elaborate long-wire arrays all work well. However, when only reception is important, and cost the major factor, a short long wire and good earth ground are hard to beat.

One good technique uses a run of RG-59/U coax to exit the building and then attach the braid to a good earth ground. From this point, attach a length of wire to the center conductor and run it as far as possible. On small lots, running around the perimeter of the property gives good results. One leg of a dipole antenna may work well, but make certain that baluns and matching networks don’t attenuate at 60 kHz. Power lines and color television sets generate significant interference at VLF, so locate the antenna as far away from these sources as possible.

Neither height nor great length is absolutely necessary. Even at my rather fringe location, I have received usable signals on a 30-foot wire running across the basement floor. My primary antenna is somewhat
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longer and made of well-insulated wire buried 3 feet underground!

In every case, a good (but not necessarily elaborate) earth ground is essential.

propagation

For about an hour, around sunrise and sunset along the main propagation path, signal strength and phase coherence are unreliable. During daylight hours (high sun angles) signals arrive entirely by ground wave and measurements performed then are theoretically most accurate. However, daytime weather along the route and noise spikes from power lines may be problems at times.

At night, particularly at some distance, sky wave propagation is a factor. Initially, ground and sky wave may be of near equal strength, alternately canceling and reinforcing one another, giving rapid phase shifts, and affecting reliability. Later, sky wave can dominate, providing significantly higher signal strengths while weather noise decreases. This improved signal-to-noise ratio makes the binary information easier to decode, although the varying path length will affect accuracy.

circuit description

The actual circuit design (see fig. 2) is straightforward with only a few necessary subtleties. Q1, Q2, and Q3 are used as variable gain amplifiers, which along with T1, T2, T3, and T4 form an RF amplifier having moderate selectivity. Q4 and Q5 have emitter-base junctions wired back-to-back, which clip the peak output voltage and along with Q6 derive an AGC voltage that is fed back to gate 2 of the MOSFETs. The AGC time constant is selected to prevent noise spikes from desensitizing the amplifier while being slow enough not to demodulate the a-m signal. A 100-ohm 1/2-watt resistor with back-to-back diodes is included at the input for lightning protection. The AGC voltage is available at TP1.

construction

At VLF layout is not critical and any reasonable materials, including perfboard, may be used. I prefer to build on one side of a copper-clad board and tack solder all components to this surface. Major components are glued or soldered to the surface and smaller pieces suspended in between. With care and practice, circuits can be quickly assembled, easily modified, and result in a finished product of surprising mechanical stability.

To begin construction, drill four holes in a row about 1 inch (25 mm) apart and ream them out to snug fit coils T1 to T4. Make their bases level with the working surface. Bend those terminals that need to be grounded 90 degrees and solder directly. Capacitors and diodes can be soldered from the proper lugs to ground with short leads. Suspend the 40673 MOSFETs upside down by the coil lugs for the gate 1 and drain, the 100-ohm source resistor and bypass for the source, and the bypass capacitor for gate 2. Take care that the case doesn't actually contact ground. The other components are suspended between the MOSFETs and the circuit board. The board can be used for support wherever a bypass capacitor is needed. Connect power and the test point (TP1) by feedthrough capacitors and the input and output signals by coax connectors or phono jacks.

alignment

Verify the wiring. Now connect a jumper between TP1 and ground to reduce the receiver gain to a minimum. Apply 12 to 15 VDC and check the current (should be 10 to 15 mA). Check the voltage from source to ground at each transistor. This should read between 0.2 and 0.4 VDC.

Connect a 60-kHz frequency source to the input and connect an oscilloscope to the output. An audio oscillator can be used, but be careful that the frequency is within 100 Hz. Peak the coils starting with T4 and work backward, reducing the input when necessary to keep all stages in a linear range.

If there is a problem, connect the oscilloscope to gate 1 of Q2 and peak T1 and T2. Then move the probe to Q3 and peak T3. At this point reconnect to the output and retune T4 through T1. When properly tuned, selectivity is sharp and there will be a rapid drop-off as the test oscillator is tuned off frequency.

At this point the receiver is ready for operation. Make certain you have a reference signal that can trigger the scope and is at a suitable submultiple frequency. To check this, connect the audio oscillator to the vertical input and with the sweep time at about 5 microseconds/cm, see if the sine wave can be frozen (synchronized) as the frequency is edged through 60 kHz.

Now connect the antenna to the receiver's input and the output to the vertical channel of the oscilloscope.
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(see fig. 3). WWVB should appear after the AGC level adjusts.

WWVB locking problems

There are many factors that frustrate attempts to directly phase lock an oscillator to WWVB. The most obvious is that the signal is erratic during certain times of the day and a tight locking scheme could go awry. Secondly, for identification purposes, the signal phase is advanced 45 degrees at 10 minutes past each hour and returned at 15 past. There will be instability unless offset circuitry is included. To avoid instability and other problems, you must start with a standard that is capable of maintaining short term stability of 0.0001 ppm (parts per million) per day or better. Compare the phase daily when ground wave is dominant and compute the aging rates. Error correction information can then be fed back digitally to the oscillator control whenever necessary, irrespective of signal conditions.

A more practical solution is to build or access the most stable oscillator possible and use this circuit to verify accuracy and, if necessary, make periodic adjustments using WWVB.

Conclusion

WWVB can be received at most locations in the United States using minimum circuitry and reasonable antenna systems. With an oscilloscope and a few divider ICs almost any oscillator can be calibrated to 0.01 ppm or better. Calibration and temperature compensation of oscillators are facilitated because both the amount and the direction of frequency error are conveniently displayed.

Sources of parts

Digi-Key Corp., POB 677, Thief River Falls, Minnesota 56701
Jameco Electronics, 1355 Shoreway Road, Belmont, California 94002

Bibliography


Ham Radio
the "radio ground" on 160 meters

My good friend Stew Perry, W1BB, is an avid 160-meter operator. He once told me that a fine "top-band" compromise antenna for hams with little space was an extended Marconi working against a good ground system. Taking his advice, I put up a 165-foot, series-tuned long wire (resonant at 1500 kHz) working against ground (fig. 1).

The ground consisted of the cold water copper pipes in the house, plus two ground rods — one at each end of the house — and a single quarter-wave radial wire running through the bushes about 2 feet above the ground.

This antenna worked quite well. However, when I went on 160 the ceiling light in the family room lit up! Obviously, the rf was getting into the house wiring somehow.

Using an MFJ-206 Antenna Current Probe, tuned to 160 meters, I started "sniffing" the house wiring for rf energy. Aha! I could put the transmitter on low power, lock the key, walk through the house with the probe, and actually trace the electric wires hidden in the walls. The house's whole electrical system was "hot" with rf.

My first thought was that the wiring was picking up induced rf energy merely by being in the near field of the antenna. But the amount of rf measured seemed too high, considering the physical separation of the Marconi antenna from the house. If this was not the path, what was?

The probe indicated that the power cable to the transceiver was full of rf energy. Most confusing. The rig actually had two grounds on it, didn't it? They were the radio ground system I installed, plus the neutral and ground conductors of the power line (fig. 2). A little thought revealed the problem.

separating the radio and electrical grounds

Figure 2 shows that two ground points exist: the intentional radio ground at the equipment, and the electrical ground at the power distribution transformer. The latter serves as a radio ground, as rf ground currents in the antenna circuit return via both paths. The unwanted path through the power cable is closely coupled to the other power conductors and feeds rf energy into them. And, if the power wiring has appreciable impedance at 160 meters, any rf fed into the power line can wander into some very unlikely places.

My solution was to wind the line cord of the transceiver around a ferrite rod (Amidon R-33-050-750), 7-1/2 inches long, and 1/2 inch in diameter. This was held in place by two plastic cable wraps. The rf antenna current immediately increased 30 percent (!) after the line choke was installed. Encouraged by this success, I took an 8-foot extension cord, wrapped it around another ferrite rod, and placed it in series with the first line choke. This increased the antenna current an additional 5 percent and the family room light did not go on when I hit the key.
I “sniffed” the house wiring with the probe again. There was still a little rf present, but it was greatly reduced. It looked as if the problem was solved.

**problems with a linear amplifier**

Now that everything had cooled off, I decided to put my 160-meter, home-made linear amplifier on the air. It uses a single 3-500Z and runs about 1-kW PEP input.

As I fired it up, a loud cry came from the other end of the house. The family room lights magically turned themselves on, along with the light in the entry hall!

Since I had used up all my ferrite rods, I found a fine industrial rf filter for the 240-volt line in the junk box. It was a well-known brand built in a nice plastic box with heavy conductors on each end (fig. 3). Unfortunately, placing it in the power line to the amplifier made no difference in the amount of rf in the power line.

It seemed that the impedance of the power line neutral wire was sufficiently high at 160 meters to allow the neutral to rise above rf ground at the filter. If this guess was correct, the capacitors in the filter served merely to bypass the rf around the line chokes.

Grounding the common point of the capacitors to the radio ground at the amplifier helped but did not solve the problem. Now the amplifier had a radio ground point, plus two power line ground points: one at the distribution transformer and a second at the transmitter radio ground. This complex grounding situation left me uneasy, so I tossed out the 240-volt line filter and wrapped the power cord to the amplifier around two ferrite rods held together with plastic tape. (I used two rods because the amplifier power cable was heavy and difficult to wrap around a single rod.)

I was happy to note that the lights no longer blinked as I keyed the amplifier. All was as it should be. Thus I learned that when a Marconi antenna is used, the ground system may be more complex than it looks. It is important to decouple the power line from the rf ground system, and the easiest way to do this is to wrap the power cable around a ferrite rod. The old-style line filter made up of inductors and capacitors just doesn’t do the job if the neutral line is used as the filter return ground point.

**a two-band dipole antenna**

Much is written about two-band antenna designs using tuned traps in the radiating element. A different approach is shown (fig. 4) in a design by Ron May, VK1PM.

This dipole covers the 80 and 40-meter bands. On 40 meters, the center section of the antenna acts as a folded dipole with a feedpoint impedance of about 300 ohms. The end sections, each a quarter wavelength long, are decoupled from the antenna and act as linear traps. On 80 meters, the full length of the antenna forms a half-wave element, fed with a T-match to the 300-ohm feedpoint. A 300-ohm TV-type feedline, with a 6:1 balun at the end, is used to match a nominal 50-ohm feedpoint (Palomar PB-6 balun). A coax line runs from the balun to the station. Overseas Amateurs using 75-ohm coax can use a 4:1 balun.

The idea can be applied to any two harmonically related bands, such as 40/20, or 20/10 meters.

**HB9ADQ delta loop for 7/14/21/28 MHz**

The delta loop shown in fig. 5 can operate on four bands. Maximum current is in the horizontal wire for best low angle radiation. The loop can be slung between two trees for ease of installation. Maximum radiation is at right angles to the plane of the loop (into and out of the page).

The loop is fed with a two-wire transmission line. The original design called for a 600-ohm line, which could be made up easily by any old-timer who has had experience building a Zepp antenna. Modern substitutes are the Saxton Products Corp. 1562 insulated open wire line (using a polyethylene web) or the 2500 open-air line. The length of the line is adjusted for minimum SWR on the coax feedline. When the 600-ohm line is used, a 20-pF capacitor is connected across the feedpoint.

The open wire line can be extended to reach the station where it is fed with an antenna tuner that provides balanced output in the range of 100 to 600 ohms.
fig. 5. Four-band loop for 7/14/21/28 MHz. Balanced feedline and balun provide match to 50-ohm coax. Adjust length of two wire line for lowest SWR on coax.

The loop need not be in the vertical plane. It can be laid on the side or at a 45 degree angle and still do the job.

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OSI/RM levels and the AX.25 packet radio protocol

This is the second article in a three part series on networking and protocols in amateur packet radio. Last month I introduced the subject of networks and protocols with examples of various systems.

Part 2 gives more detailed information on the initial layers of the OSI/RM introduced in Part 1 and their relation to amateur packet radio. Also examined is the AX.25 packet radio protocol. Portions of this series are excerpted from my book, The Packet Radio Handbook.*

OSI/RM and amateur packet radio

There are three levels of OSI/RM (Open Systems Interconnection Reference Model) currently implemented in amateur packet radio in the United States: the physical, data link, and rough forms of the network layer. We will discuss the first two. Levels and protocols now under development will be covered in Part 3.

physical layer

The physical layer is well prescribed and the Bell 202 and 103 are its most widely used modulation standards. The RS-232C asynchronous serial interface is another physical layer standard and more should emerge when high speed modems and new modulation schemes are developed.

Encoding technique is an area of the physical layer involved in transmission of data which defines the format of the modulated signal. In RTTY and Amateur packet radio, a bipolar format is used. In bipolar keying, two different levels are used to represent a 1 and a 0. This is an improvement over unipolar keying where a single tone indicates a 1 and the absence of a tone a 0. (See fig. 1.)

Bipolar keying takes several forms. NRZ (NonReturn to Zero) or NRZ-L (NRZ-Level) is used by regular Baudot RTTY and AMTOR. In NRZ, a 1 is represented by a particular level or tone, and a 0 by another. See fig. 2.

NRZ-I (NRZ Inverted) or NRZ-S (NRZ Space) is the bipolar method employed by most packet radio stations and supported by all manufactured TNCs. In NRZI, a binary 0 causes a switch (or transition) between signal levels while a binary 1 remains at the current level. The two signal levels can also be referred to as “mark” and “space” levels.

Other forms of bipolar keying encoding techniques are: NRZ-M (NRZ-Mark; the opposite of NRZ-S), PPM (Pulse Position Modulation), PDM (Pulse Duration Modulation), and Manchester I and II. These and other encoding techniques are discussed on pages 19-39 of the 1986 ARRL Handbook.

data link layer

The data link layer in amateur packet radio is also well prescribed. The AX.25 protocol is the most common and is supported by the majority of commercial TNCs. The V-1 (VADCG—Vancouver Amateur Digital Communications Group), and V-2 protocols are other data link layer protocols. These differ from AX.25 in many respects, however, all three protocols are based on the HDLC ISO standard.

HDLC

High-level Data Link Control (HDLC) is the data link layer (level 2) of X.25 and is defined in the following ISO standards: ISO 3309, ISO/DIS 4335, ISO/DIS 6196, and ISO/DIS 6259. HDLC is responsible for

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delivering error free data throughout the network. It also isolates the upper levels from the physical layer. Data is broken up into blocks (frames) for transmission. The user data (actual data sent through the network by the users) is called data or information.

HDLC consists of three sublayers: 1) transparency of the bit stream, 2) frame format, and 3) cooperation between stations. Before continuing this discussion of HDLC, an explanation of the differences between COPs and BOPs is necessary.

COP stands for Character Oriented Protocol. Two examples are ANSI X3.28 and IBM Binary Synchronous Communication. In a COP, the data being sent must be represented as characters of specified length — usually seven or eight bits (one byte) — so there is a limit to the type of information that can be transmitted. All transmission lengths must be a multiple of the specified character length. COPs are helpful if just text is being transmitted, but less useful in packet radio which is designed to send any type of digital data including characters of different lengths, graphics, and special formats. In packet radio, transmission size must also be condensed as much as possible. BOPs (Bit Oriented Protocols) come in handy here.

BOPs permit the transmission of any format of digital data. A good example of a BOP is HDLC along with the amateur packet radio data link layer protocols. If control information is only 3 or 4 bits long, BOPs will only consume 3 or 4 bits, not a full 7 or 8 as COPs do.

In the first sub-layer of HDLC, transparency of the bit stream, all data being transmitted must be packaged the same. HDLC must be independent of the data sent and simply delimit (mark the beginning and end) frames. No special length bits or signaling elements can be used and all data should pass through the physical layer without alteration or processing. A flag — a special binary sequence found only at the beginning and end of a frame — is used to do this. The flag used in HDLC is 01 11 11 10 and must not appear anywhere else in the frame.

To keep flags out of the user data, the information is examined, and a 0 is inserted after every five consecutive 1 bits. This is called bit stuffing. The receiving station corrects for this by removing the stuffed bit after a sequence of five 1s if it is a 0; if the bit is a 1, it will not be removed as the sequence of ones is part of a flag.

In the second sub-layer, the frame format, all data is segmented and sent in frames delimited by flags. The components of the frame between the two flags are: addresses, control information, data, and the FCS (Frame Check Sequence). Figure 3 shows the HDLC frames. Frame components are described below.

The first frame component following the initial flag is the address. In HDLC this includes the address of the originating and destination station. The addresses are usually numerics, but AX.25 uses call signs instead of numbers and includes digipeaters in this section.

The next section (or field) in the HDLC frame is control information. Depending on the type of frame, control information can consist of several things. The three types of frames defined under HDLC are: information, supervisory, and unnumbered. The control field is made up of 8 bits.

Information frames are used for data transfer (to carry user information). Bit 1 of the control field of an information frame is a 0, bits 2 through 4 represent the transmitting station sequence number (often called transmit count), bit 5 is the poll/final bit, and bits 6 to 8 represent the receiving station sequence number (receive count).

Supervisory frames are used to control data flow.
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Bit 1 of a supervisory frame’s control field is a 1, bit 2 is a 0, and bits 3 and 4 represent the supervisory frame type indicator. Bit 5 is the poll/final bit, and bits 6 to 8 show the receive count.

Unnumbered frames control the link. Bits 1 and 2 of the control field of an unnumbered frame consist of ones, bits 3 and 4 are modifier bits, bit 5 is the poll/final bit, and bits 6 to 8 are modifier bits.

Each station involved in a link maintains counters for the number of information frames sent and received. These counters are the “sequence number” or “count”. They are sent in the control field of each information frame, and used to check the sequence of received frames and acknowledge their reception.

The HDLC frame component next to the final flag is the FCS. The FCS is a cyclic redundancy check (CRC) performed on a frame — an error detection scheme in which a check character is generated by dividing the entire numeric binary value of a block of data by a generator polynomial. The FCS value is sent along with the data, and at the destination station, is recomputed from the received data. If the received FCS matches the one generated from the received data, the data is considered error free.

Computation of the FCS starts with the first bit after the opening flag and ends with the last bit preceding the FCS. For details on FCS methods, see ISO standard 3309.

Cooperation between stations, the last sub-layer, is handled by special frames recognized by HDLC as commands and responses. Three tasks of command and response frames are to establish connections, acknowledge receipt of frames, and handle disconnects. Specifics of the different commands and responses used by HDLC to manage the link layer in Amateur packet radio are discussed under the appropriate protocols.

**AX.25**

AX.25 has become the standard level 2 protocol in Amateur packet radio. It is very similar to the level 2 protocol of the X.25 standard; thus the name ‘AX.25’ (‘A’ is for Amateur). The original version of AX.25 has been around for a while and minor incompatibilities existed between various implementations until the ARRL Ad Hoc Committee on Amateur Digital Communications finished a revised version of the AX.25 standard in 1984.

The ARRL version of AX.25 is called AX.25 Version 2 and the earlier AX.25 protocol is now AX.25 Version 1. The more popular AX.25 Version 1 protocol was developed by Tucson Amateur Packet Radio (TAPR). There are both similarities and incompatibilities between these versions of AX.25.

AX.25 follows the same frame format as HDLC. The main differences are that 1) the address field has been extended to permit amateur radio callsigns as addresses and 2) unnumbered information frames may be transmitted.

A description of the various components of an AX.25 frame (see fig. 4) follows.

The flag is identical in function and design to that used in HDLC.

The address field is made up of a minimum of one amateur radio callsign belonging to the sending station in a unnumbered information frame (the destination is set to a dummy address). In most cases, the destination station’s callsign is included. Up to eight digipeater callsigns may also be added. There is a maximum number of ten callsign addresses in the AX.25 address field.

Each callsign requires seven groups of eight bits (eight bits = one byte = one character or an ‘octet’). Callsigns consist of uppercase ASCII characters and numbers. The first six characters are allotted for the actual callsign; if the callsign is less than six characters in length, spaces are added to the end. The seventh character is the SSID (Sub-Station IDentifier or Secondary Station IDentifier) and ranges from 0 to 15. Only four bits of the eight available for the SSID are used. The first and last bits are set to 0 and the remaining two are reserved for future use.

The SSID of a digipeater carries additional information. To avoid a digipeater repeating a frame twice, the last bit of the SSID is set to 1 once the frame has been digipeated by that station.

The control field is made up of one eight bit group (an octet) and is used to identify the type of frame: information, unnumbered, unnumbered information, and supervisory. It also contains the frame count numbers used for acknowledgements and special signals for establishing and maintaining connections (commands and responses).

A Protocol IDentifier Field (PID) is included with information frames. It identifies what kind of network layer protocol, if any, is being used.

---

**Information and Unnumbered Information Frames**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>PID</th>
<th>Info</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
</table>

**Unnumbered and Supervisory Frames**

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
</table>

---

fig. 4. AX.25 frames. The numbers in each field represent bits. The address field can contain a minimum of 112 bits (two callsigns at 56 bits each) and up to 660 bits (two callsigns plus eight digipeaters). The largest information field is 2048 bits.
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The information field contains the user data being transmitted and is most often divided into a multiple of octets; the maximum is 256.

The FCS is the same as that used in HDLC.

Each transmission is usually preceded by a series of sixteen alternating bits giving the receiving station time to synchronize to the signal.

AX.25 is actually a subset of the HDLC standard as it does not implement the full range of features defined in HDLC. It is based on the LAPB (Link Access Procedure Balanced) subset of HDLC.

In a "normal" HDLC network, there are frequently several slave stations (user terminals) linked to a central controller or host system (also called a primary or master station). The master station is usually more "intelligent" than the slave stations and better able to manage the link. This configuration, with one intelligent master station linked to a less intelligent slave station, is unbalanced because the stations possess unequal capabilities.

In amateur packet radio, the goal is for each station to have equal capability in a balanced configuration eliminating the need for a master or host station. This type of station arrangement is supported by LABP under HDLC.

A discussion of the frames used by AX.25 to establish connections, acknowledge frames, and disconnect follows.

Unnumbered frame control fields are either commands or responses. Unnumbered frames handle all communications between stations when no connection has been established. There are six different unnumbered frames defined in AX.25.

SABM (Set Asynchronous Balanced Mode) is a command which sends a connect request to another station. The control field in this frame contains a special sequence of bits identifying it as a SABM frame. The SABM command places two stations in asynchronous balanced mode (meaning they are connected).

DISC, the next unnumbered frame and another command, is used to send a DISConnect request terminating a connection with another station.

DM (Disconnect Mode), is a response sent whenever a station receives any frame other than a SABM while disconnected. It can also be sent in response to a SABM frame to indicate the station is not available.

The UA (Unnumbered Acknowledge) response is sent as an acknowledgment for unnumbered frame commands. A received command is not executed until a UA frame has been sent.

FRMR (FRaMe Reject) is also a response. It is sent when a station receives a frame that cannot be processed. This response is usually sent when a frame clears the FCS check but is not recognized by the station's protocol. Two situations when this might occur are the reception of a command or response not defined in the protocol, or an information frame whose information field exceeds the maximum allowable length.

UI (Unnumbered Information) is an addition to the X.25 protocol included in AX.25. The UI frame lets an information field be transmitted without first establishing a connection. These frames are not acknowledged.

Once a connection is established using the above commands and responses, AX.25's function is to transfer error free data between the two stations. It does this by using one of three of supervisory frames.

The RR (Receive Ready) response indicates that the sending station is able to receive information frames, acknowledge the reception of information frames, and clear an RNR response previously sent by the station. The RR frame acknowledges the reception of information frames by including the receive count indicating which frames have been correctly received. The other station can examine the count and update the next packet to be sent according to what frames can now be "forgotten".

To indicate that the sending station is temporarily busy and unable to accept more information frames, a RNR (Receive Not Ready) response is sent. This might occur when the receive station's buffer is full and it sends an RNR to the other station telling it to hold further information frames until the buffer can receive them. The RNR condition can be cleared by sending a UA, RR, REJ, or SABM frame.

The REJ (REject) response requests the retransmission of information frames received out of sequence. The frame(s) to be retransmitted are indicated by the receive count in the frame's control field. The REJ condition is cleared when the frames are properly received.

AX.25 follows certain steps when connecting and disconnecting from another station.

When a user types a "C KR3T" at the command prompt and presses the RETURN key, the TNC prepares a SABM frame containing the user's call and KR3T in the address field. The TNC then checks to see if the channel is available (CSMA) and transmits the SABM frame if it is.

KR3T receives the frame and finds its call in the destination address. If connect-ok (CONOK) is on and the TNC is free to establish a connection, KR3T sends a UA frame to the originating station and is connected. If CONOK is off, KR3T sends a DM frame to the originating station.

Assuming KR3T is available and the originating station has received the UA frame from KR3T, it too becomes connected and information frames are used to transfer data between them. Both stations keep receive and transmit counters current.
The RR frame is used to acknowledge the receipt of information frames. If a frame is received out of sequence by one of the stations, it sends a REJ to the other and the frame is retransmitted.

When one of the stations wants to end the connection, it returns to command mode and enters "D" at the prompt. His TNC then sends a DISC frame to the other station which, in turn, sends a UA frame acknowledging the disconnect request and breaking the connection. When the first station receives the UA frame, it also disconnects.

A few points in the previous section on the AX.25 link layer protocol may not seem to fit the description of the data link layer given in Part 1 of this series. These discrepancies include the addition of digipeaters and the use of end to end acknowledgements.

Digipeaters seem to fall under the control of the network layer protocol, not the data link layer, and in many respects this is true. However digipeaters are not, by any means, full fledged level 3 network nodes but rather a simple arrangement added to allow for rudimentary networking. The user must select the digipeaters used; the TNC does not contain automatic routing tables or other means of independently selecting digipeater routes. Digipeaters will most likely disappear as more advanced network nodes and level 3 protocols emerge.

In the OSI/RM the end to end acknowledgements would seem to be the responsibility of the transport layer (level 4). This layer is responsible for the proper reception of frames from station to station through the network. In AX.25 there is no network layer protocol implemented yet, so point to point acknowledgements of the data link layer are simply extended over the digipeater path. If the digipeaters are eliminated from the path, the acknowledgment returns to a point to point acknowledgment as used by the data link layer. Once network nodes are implemented, they will use point to point acknowledgments between nodes and a transport layer acknowledgment between the two end stations.

summary

This article detailed the first two levels of the OSI/RM as they relate to Amateur packet radio. Also included were a discussion of HDLC (upon which most current Amateur packet radio level 2 protocols are based), and an examination of the AX.25 data link protocol. Part 3, the final article in this series will cover other level 2 packet radio protocols and discuss the remaining layers of the OSI/RM.

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parametric amplifiers

Parametric amplifiers can operate with very low noise in the UHF and microwave regions of the electromagnetic spectrum. Noise temperatures from 100 to 270 degrees Kelvin (1.4 to 2 dB noise figure) were reported in uncooled parametric amplifiers as early as 1970, and more recent devices offer even better performance. As a result, parametric amplifiers are sometimes used as low noise amplifiers (LNA) in the input stages of VHF/UHF and microwave communications receivers.

The name parametric amplifier was chosen because amplification occurs through the excitation of a circuit parameter. This is actually a misnomer because it is the reactance parameters ($X_C$ and $X_L$) that are excited. A better name might be reactance amplifier. The parametric amplifier is fundamentally different from other LNAs because it uses a passive device for amplification. In this type of amplifier circuit a reactance is used as the amplifying element. A perfect reactor stores and discharges energy, but does not dissipate power. Capacitive reactors store energy in an electrostatic field, while inductive reactors store energy in a magnetic field. Parametric amplifiers store energy from an rf "pump" signal in the reactance, and then switch it to the load under the influence of the input signal. Addition of stored energy to the signal at the output of the amplifier causes power amplification.

The parametric amplifier has low noise because reactances dissipate no power and ideally produce no Johnson (thermal agitation) noise. In practical circuits, resistive losses do occur and Johnson noise is present. By varying the reactance at a rapid rate, energy is stored and discharged by the reactance and is used to amplify the signal. Although either capacitors or inductors can be used in parametric amplifiers, the capacitive reactance is used in practical circuits because suitable voltage variable capacitance diodes ("varactors") are available. However, other processes inside a diode generate noise and while parametric amplifiers exhibit low noise factors, the level is not zero.

The capacitance of a varactor is a function of the reverse-bias potential applied across the PN junction of the diode. A typical varactor useful in parametric amplifiers has a breakdown voltage of $-4$ to $-12$ volts, and a zero-bias junction capacitance of 0.2 to 5 picofarads. The cutoff frequency should be 20 GHz or higher. Generally, noise figure improves with higher diode cutoff frequencies.

Parametric amplifiers can be operated in either of three modes: degenerative, nondegenerative, and regenerative. We will consider these modes, and provide a tool for evaluating parametric amplifier circuits.

**Degenerative parametric amplifiers**

Figure 1A shows a basic parametric amplifier. A varactor diode switches the signal on and off to the load as an external pump signal is applied. Although shown as a series connected switch, both series and parallel connected diodes can be used. The signal and pump waveform (see fig. 1B) are phased so that the diode capacitance is fully charged when the pump signal peak occurs. Because the charge is constant, the voltage increases by the relationship $V = Q/C$ in step with a pump voltage reduction of diode capacitance. Parametric amplification occurs when the peak of the pump signal coincides with the positive and negative peaks of the signal waveform. As the pump voltage peaks the diode capacitance decreases to a minimum, and the capacitor's charge is dumped to the load. Phasing must be precise to achieve degenerative parametric amplification. This occurs when the pump frequency is twice the signal frequency. However, this precise phasing requirement means that drift in either signal can reduce the gain or prevent the circuit from operating. Using nondegenerative or regenerative parametric amplifier circuits is a broader bandwidth approach.

**Nondegenerative and regenerative parametric amplifiers**

In a nondegenerative parametric amplifier a third frequency, known as an idler, $f_i$, is used in addition to the signal and pump frequencies, $f_s$ and $f_p$. In fig. 2 a third resonant tank circuit ($L_C$) tuned to $f_i$ is indicated. The idler is the output frequency of the circuit which also operates as a frequency translator or converter.

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- Weight: 710 Grams (1 lb. 9 oz.) with batteries and antenna

**Transmitter**
- Output Power: 2 Watts at 9.0 VDC
- Emission modes: A3J (USB) and A1 (CW)
- Spurious Emissions: More than 40 dB down

**Receiver**
- Sensitivity: less than 0.5 uV for 15 dB S/N
- Intermediate Frequency: 11.2735 MHz

**Controls and Indicators**
- On/Off Volume control Top mounted Potentiometer
- Receiver Incremental Tuning (RIT): Top mounted Potentiometer with center off detent position
- Frequency: Top mounted 50 KHz VXO
- Frequency Range: Top mounted 2-position switch
- Noise Blanker: Top mounted On/Off switch
- S:RF meter: Top mounted S:RF meter
- Built in CW key: Top mounted momentary switch
- External Speaker output: Top mounted 1/4" phone jack
- External Microphone input: Top mounted 1/4" phone jack
- Antenna Connector: Top mounted Female BNC
- Transmit Indicator: Top mounted Transmit LED
- Push-To-Talk: Side mounted momentary switch
- External Power: Bottom mounted 2.1 mm coaxial
- External key Input: Bottom mounted 1/8" phone jack
- Mode Selector Switch: Bottom mounted 2-position switch
- Charge/External Power: Bottom mounted 2-position switch selecting 12 VDC external power function

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**March 1988**
degenerative parametric amplifiers: upconverters and downconverters. In the upconverter the idler frequency is the sum of the pump and signal frequencies:

\[ f_i = f_s + f_p \]

In the downconverter, the idler frequency is the difference between pump and signal frequencies:

\[ f_i = f_s - f_p \]

Power gain is defined as the ratio of the output to input power. In the case of a lossless circuit the gain of the upconverter \((f_i > f_s)\) is:

\[ G = \frac{f_i}{f_s} \]

The downconverter actually shows a loss (attenuation), rather than a power gain.

The third category of parametric amplifiers is the regenerative circuit, and is actually a special case of the nondegenerative amplifier. In the regenerative amplifier the pump frequency is the sum of the signal and idler frequencies. The power transfer direction is reversed, implying a negative resistance characteristic and the resulting circuit is regenerative. If prevented from oscillating, low noise and very high gain are achieved.

noise in parametric amplifiers

The low noise capability of the parametric amplifier results from the use of a reactance instead of a resistance for the amplifier element. In an ideal parametric amplifier the noise figure is zero.

Manley-Rowe relationships

In 1957 Manley and Rowe developed a way to evaluate parametric amplifier circuits.\(^*\) Consider the equivalent circuit in fig. 4. We have a variable capacitance as the element and two signal sources: the signal frequency \((f_s)\) and the pump frequency \((f_p)\), both shown as generators. Filters in series with both generators pass the generator frequency and reject all others. There is also a series of loads, each isolated from the others by the same kind of ideal narrowband filter. The frequencies of these filters are: \((f_s + f_p)\), \((f_s - f_p)\), up to \((m f_p + n f_s)\) (where \(m\) and \(n\) are integers). The Manley-Rowe relationships are:

\[ \sum_{m,n} \frac{m P_{m,n}}{mf_p + nf_s} = 0 \]  \( (5) \)

\[ \sum_{m,n} \frac{n P_{m,n}}{mf_p + nf_s} = 0 \]  \( (6) \)

In working with Manley-Rowe equations, the following algebraic sign conventions regarding power are used:

- \(+ P\) is assigned to power flowing either into the capacitor, or from the pump and input signal "generators," and

- \(- P\) is assigned to power flowing out of the capacitor or into a load resistance.

The parametric amplifier's stability is determined by the sign of the power flowing with respect to the capacitor. If the power from the signal flows into the capacitor, the stage is stable. Because we deal with integers from 0

\(^*\)See Liao and Coleman for discussions of Manley-Rowe relationships. The Liao book derives the equations, while Coleman works out several examples.
through the \( i \)th, we can check not only the fundamental frequencies \((m, n) = (1, 1)\), but also their respective harmonics \((m, n > 1)\). Some of these combinations are stable; others are not. There are several cases where the Manley-Rowe equations apply. Let's consider only one to see how such problems are solved.

**Example**

Consider a parametric amplifier in which an output frequency \( f \) is the sum of the pump signal \( f_p \) and the input signal \( f \) frequencies: 

\[ f = f_p + f \]

Solve the Manley-Rowe equations to determine network stability.

**Solutions**

First construct a table showing the signals and permissible values of \( m \) and \( n \) (we will consider only the fundamentals).

**SIGNAL**  
\[ m \quad n \quad mf_p + nf_s = ? \quad P_{m,n} \]

<table>
<thead>
<tr>
<th>Input</th>
<th>( m )</th>
<th>( n )</th>
<th>( mf_p + nf_s )</th>
<th>( P_{m,n} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>1</td>
<td>0</td>
<td>( f_s )</td>
<td>( P_{10} )</td>
</tr>
<tr>
<td>Pump</td>
<td>0</td>
<td>1</td>
<td>( f_p )</td>
<td>( P_{01} )</td>
</tr>
<tr>
<td>Idler</td>
<td>1</td>
<td>1</td>
<td>( f_p + f_s )</td>
<td>( P_{11} )</td>
</tr>
</tbody>
</table>

The first case (Manley-Rowe I) can be rewritten in the form:

\[ \frac{P_{10}}{f_p} = -\frac{P_{11}}{f_p + f_s} \]  \( \text{(7)} \)

\( P_{11} \) is negative because \( P_{10} \) is positive by definition (it is the pump signal). We also know that \( f_p + f_s \) is always positive, so the negative sign is associated with \( P_{11} \).

For the second case (Manley-Rowe II):

\[ \frac{P_{01}}{f_s} = \frac{-P_{11}}{f_p + f_s} \]  \( \text{(8)} \)

Since \( P_{11} \) was defined as negative, by the same reasoning \( P_{01} \) is positive. Because \( P_{01} \) is positive, *signal power flows into the reactance*, and the circuit is stable. (A negative power term for the signal would denote instability.)

Either inductors or capacitors can be used as reactive elements in a parametric amplifier. In 1957 Suhl\(^5\) and Weiss\(^6\) proposed the use of ferromagnetic inductors in microwave amplifiers. Practical considerations favor the voltage variable capacitance diode ("varicap") as the reactance in parametric amplifiers. These devices work to frequencies above 20 GHz, and because they are voltage variable capacitors, make actual circuit implementation relatively easy. Varicaps operate in the reverse-bias zone of the I versus V curve, and tend to have low avalanche potentials. This ease of circuit implementation is gained at the

\[ \text{fig. 3. Microwave parametric amplifier.} \]

\[ \text{fig. 4. Equivalent circuit used to model Manley-Rowe relationships.} \]
expense of Johnson and other diode noise terms.

**Inductor-based superconductive parametric amplifiers**

New superconductivity technology based on metallic ceramic materials has been reported. Researchers have achieved superconductivity states at relatively high temperatures (about 95 degrees K, with some promise of 225 degrees K). The use of inductive reactances in parametric amplifiers is under reconsideration based on recent research. Several points are worth noting:

- Lower loss resonant circuits for signal, pump, and idler frequencies in conventional varicap-based parametric amplifiers (and perhaps lower achievable noise figures).
- Improved switchable inductors that operate at microwave frequencies, and make possible inductor-based parametric amplifiers.
- New forms of switchable energy storage devices that could replace present reactances in parametric amplifiers. Although one tends to think in traditional terms about inductive and capacitive reactances, perhaps a new type of reactance is possible. The strange behavior of superconductors with respect to magnetic fields may prove promising.

A phenomenon noted as early as 1947 may be of interest in the latter case. Kinetic inductance produces inductance-like effects caused by the mass inertia of charge carriers in the material. In non-superconducting materials, ordinary magnetic inductance swamps the effects of kinetic inductance. In superconducting materials, however, magnetic inductance collapses leaving the kinetic variety.

The conventional (varicap-based) parametric amplifiers are limited by their small dynamic range, due to the characteristics of the varicap diode used for the reactance. It may turn out that inductor-based devices will exhibit improved dynamic range.

One reason parametric amplifiers do not use superconductive technology is because the equipment needed to achieve the required near Absolute Zero temperature is expensive and large. This situation may change as progress is made in high temperature superconductivity.

**References**

4. ARRL *VHF Manual*.
8. Ibid.
microwave components and terminology: part 1

From time to time I've featured microwave topics in this column. Most dealt with the present state of the art (SOA) but some gave a glimpse at older microwave components or terminologies.

The SOA changes so rapidly that many of the components once necessary for microwave systems have become extinct, been replaced, or moved upward in frequency. In light of this, I thought it would be a good time to discuss the basic microwave components of the past and present. This will make future developments easier to understand.

The subject of microwave components is extensive. Entire books have been written on single components such as waveguides. In this month's column, I will concentrate on micro-wave transmission lines and related components and build upon this information next month, in addition to describing some other common microwave features.

microwave transmission lines

A transmission line is a system of material boundaries forming a continuous path from one location to another. In radio communications from low frequencies through UHF this usually refers to a balanced line, coaxial cable, stripline, or microstrip transmission line. From UHF up through the microwave and millimeter wavelengths a waveguide or G-line is often used.

Transmission lines have many different properties. The most important for Amateurs are the impedance, insertion loss, power handling capacity, and velocity of propagation. These terms are described in detail in reference 1.

Balanced lines, often referred to as open wire, twin lead, or ladder lines, were the first type of transmission lines. They became popular when commercial television was introduced but have largely been replaced by coaxial cable.

coaxial transmission lines

Coaxial cable was invented in 1921 by Lloyd Espenschied and Herman A. Affel at the AT&T Engineering Labs in New York City. Nowadays it is by far the most common transmission line because it is easy to use, low cost, and operates over a wide frequency range. But, as frequency increases, so does the insertion loss. In general, the larger the diameter and the lower the dielectric loss (air is the lowest), the lower the insertion loss. Reference 1 gives information on typical insertion loss versus frequency.

Coaxial transmission lines normally consist of two conductors, often described as operating in the TEM (transverse electromagnetic mode or field pattern). This means that both the electric and magnetic fields are transverse or perpendicular to the axis of the line as shown in fig. 1A.

When spacing between the two elements in a coaxial transmission line exceeds one-half the operating wavelength or the circumference of the inside of the outer conductor exceeds one wavelength, energy can propagate down the transmission line in other than the desired mode. This is usually referred to as a higher order mode. The following formula quickly determines the maximum usable frequency below which higher order modes will not occur:

\[ f_{co} = \frac{7.5}{\sqrt{\varepsilon_r (D + d)}} \]  

\( f_{co} \) is in GHz, \( \varepsilon_r \) is the dielectric constant (air = 1.0), D is the inside diameter of the outer conductor, and d is the outside diameter of the inner conductor — both in inches. For example, a 50-ohm Teflon™ coax line, \( \varepsilon_r = 2.1 \), with D of 0.120 inches and d of 0.036 inches would be usable to at least 13.1 GHz.

In the last two decades, there has been much research and development in the field of coaxial transmission lines. Improved coaxial cables are smaller, more precise in impedance characteristics, and have lower loss. There are now commercial coax transmission lines that operate beyond 20 GHz.

Two of the most common microwave coax types used by Amateurs are the semi-rigid 0.141 and 0.085 inch outside diameter Teflon dielectric
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Shpg. Wt. 3 lbs...

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50-ohm coax that manufacturers claim can operate to 30 and 55 GHz, respectively. Attenuation at 20 GHz is typically 60 and 100 dB per 100 feet for the two cables, respectively.

microwave strip transmission lines

The concept of strip-type transmission lines was discovered during World War II, and in the mid-1950s the first practical designs were introduced as “Tri-Plate.” These first strip transmission lines were a balanced structure with a “sandwich” construction and operated in the TEM mode similar to coaxial transmission line.

Microstrip, a sort of open-faced sandwich version of stripline, followed and is widely used well into the microwave region. Glass PCB, G-10, can be used but is lossy at microwave frequencies. Lower loss dielectrics like Teflon-impregnated glass laminates and low-loss ceramics are available as are new types of structures — fin-line and suspended substrate, to name two.

waveguides

When you think of microwaves, what probably comes to mind are those bulky waveguides and waveguide components. In the “good old days,” microwave engineers were often referred to as “plumbers” because they worked mainly with waveguides and other materials that resembled pipes and plumbing.

The practical uses of waveguides as transmission lines were discovered independently and almost simultaneously by W.L. Barrow and G.C. Southworth in 1936. The breakthrough was one of many making radar and microwaves possible. Waveguide transmission lines have been used at frequencies below 200 MHz to well above 150 GHz!

There are four basic waveguide cross-sectional geometries: rectangular, square, elliptical, and circular. Each type has specific electrical properties and preferred usage.

Rectangular waveguide is probably the most common since it has the widest operating bandwidth. Its width is usually twice its height (see fig. 2A).

Square waveguide shown in fig. 2B is sometimes used in applications like dual polarized feeds and horns. However, since its height and width are the same and there is mode isolation, it is difficult to use.

Elliptical waveguide (fig. 2C) is often used where flexible runs are required — especially if it is corrugated and the run to be used is between 1.9 and 15 GHz. It is usually easier to install than rectangular waveguide but does have somewhat higher attenuation.

Circular waveguide (fig. 2D) has very low attenuation — sometimes only half that of rectangular waveguide — so it is often used on long, straight vertical or horizontal runs. Its circular nature allows two orthogonal modes to be propagated simultaneously, but this same circular symmetry can cause the polarization to rotate as the wave travels down the guide.

waveguide modes

A waveguide is a transmission line
where the wave propagation is not in TEM mode form. Waveguides appear to be simply a hollow tube with walls acting as a single conductor. Therefore, their operation is quite different from coaxial lines. Waveguides are mostly used as transmission lines but have other uses; these will be discussed in next month's column.

Waveguide transmission lines usually operate in a TE (transverse electric) mode in which the electric field is always transverse to the direction of propagation and transverse to the axis of the waveguide at all locations. Waveguides sometimes operate in the TM (transverse magnetic) mode in which the magnetic fields are everywhere transverse to the axis of the waveguide.

Unlike coaxial transmission lines which are not sensitive and can usually be operated from dc up to their cutoff frequency, waveguides are very frequency sensitive. Each geometry has a different cutoff wavelength or minimum frequency that can be propagated and below which the insertion loss is very high.

If the operating frequency is higher than some critical value determined by the dimensions and the geometry of the guide, the wave will propagate down it with low attenuation. If the wavelength is greater than this cutoff value, the waves in the waveguide die out rapidly in amplitude even if the material in the walls of the guide has infinite conductivity.

The mode for which the cutoff wavelength is greatest is the dominant mode (desired mode for transmission lines), since it has the least insertion loss. In a rectangular waveguide, it is often referred to as the TE_{10} mode.

The subscript "1" means that the field distribution in the direction of the long (cross-sectional) side of the waveguide contains one-half cycle of variation. The subscript "0" indicates that there is no variation in either the electric or magnetic field strength in the direction of the short side of the guide. The TE_{10} field pattern in a rectangular waveguide is shown in fig. 1B.

The width of a rectangular waveguide at the cutoff frequency is approximately half that of the free space wavelength. For example, the free space wavelength at 2.3 GHz is approximately 5.123 inches. Therefore, the width of a rectangular waveguide at this frequency must be at least 2.561 inches.

For minimum loss it is best to operate in the dominant mode, which is about 25 percent higher in frequency. Here the optimum width of a rectangular waveguide at 2.3 GHz would be 25 percent wider, or about 3.2 inches. The dominant mode in a circular waveguide is the TE_{11} mode. Figure 1C shows its field pattern. Cutoff frequencies are different for circular and rectangular waveguides. The circular waveguides also have modes that are closer in frequency than those of rectangular waveguides so they have narrower mode-free bandwidth.

In general, the diameter of a circular waveguide needs to be slightly larger than the width of an equivalent rectangular waveguide to work at the same frequency. See reference 5 for additional design information for circular waveguides.

The impedance of a coaxial line is constant. In waveguides, impedance changes with size, mode, and frequency and is not easy to determine. If operating in the dominant mode in rectangular waveguide, the impedance is generally in the 350-to-600 ohm region.

Because waveguides are specifically intended for high frequency operation, the conductivity of the walls is very important and plating is usually used. The plating need not be thick since the skin depth is shallow — often less than 0.001 inches above 1.0 GHz.

Table 1 shows the resistivity and relative conductivity of some commonly used waveguide materials and plating. Copper and silver-plated copper are preferred.

Waveguides have standards and a part numbering system just like coaxial cables. See table 2 for some of the standard rectangular waveguide types and their important physical and frequency characteristics.

Amateurs often use waveguides on the microwave bands. They cost little on the surplus market and have low loss, especially when used for antenna feed systems. Compared to coax, the loss of WR-90 waveguide is 4.5 to 6.5 dB per 100 feet over its operational frequency range of 8.2 to 12.4 GHz. A more complete list of the stan-

<table>
<thead>
<tr>
<th>Table 1. Resistivity and relative attenuation of some common metals or platings used in transmission lines at RF frequencies.</th>
<th>Table 2. Rectangular waveguide characteristics.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Resistivity (ohms cm x 10^-6)</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.62</td>
</tr>
<tr>
<td>Brass (66 Cu 34 Zn)</td>
<td>3.9</td>
</tr>
<tr>
<td>Copper (commercial annealed)</td>
<td>1.7241</td>
</tr>
<tr>
<td>Gold</td>
<td>2.44</td>
</tr>
<tr>
<td>Silver</td>
<td>1.62</td>
</tr>
<tr>
<td>Steel (stainless)</td>
<td>90</td>
</tr>
</tbody>
</table>

Waveguide Outside width Outside height Wall thickness Frequency range
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March 1988
Attenuation is a linear function and not frequency sensitive if operated sufficiently below the cutoff frequency. For example, a circular waveguide 0.5 inches in diameter and 0.5 inches long will have an attenuation of approximately 32 dB and 96 dB at 1.5 inches. A simple and accurate mechanical attenuator can be designed. One example is the output attenuator on signal generators like the Hewlett-Packard 608 (10-450 MHz).

Amateurs can also use waveguides beyond cutoff in high-power amplifiers at the entrance or exit for the air delivery system, where rf could leak and any restrictions will cause the tube to overheat. Often a group of five to ten smaller tubes (e.g., 0.5 inch diameter) are grouped together to reduce the required length of a single large diameter tube, as shown in fig. 3B.

Today waveguides and microwaves are not always seen as synonymous and the SOA is changing so rapidly that coaxial components are starting to dominate the microwave field (at least up through 10 to 20 GHz). References 5 and 6 discuss microwave transmission lines and waveguide use in detail.

microwave connectors

Whether you use coaxial or waveguide transmission lines, you will probably need connectors. Special coax connectors have been developed for use as high as 34 GHz.*

Waveguides have connectors called “flanges” (Fig. 4A). They are butting joints similar to plumbing unions and can be held together with ordinary machine screws as shown in Fig. 4B. Sometimes these flanges do not join perfectly, causing rf leaks or impedance discontinuities. To prevent this, “choke” flanges with quarter-wavelength slots like those in Fig. 4C have been developed.

transitions and junctions

Sometimes it’s necessary to connect one waveguide size to another, just as you may interconnect an RG-8/U with an RG-17/U coax through a coax adapter. You might also want to change from a rectangular to a circular waveguide, or from a waveguide to a coaxial line. You can accomplish this with a transition device.

When connecting waveguides of different sizes, remember they will each have different impedances. If you were to operate at only one frequency you could design a quarter-wavelength waveguide transformer; but this would require tight mechanical tolerances that are difficult to maintain at these frequencies.

For this reason, waveguides of different sizes with common frequency ranges are often joined through a tapered section or transition. It is also desirable to have a transition to interconnect a circular and rectangular waveguide. Typical transition is shown in Fig. 5A.

For a smooth change with minimum impedance discontinuities, transitions should occur over at least a wavelength. Typical losses in commercial circular to rectangular waveguide transitions are 0.1 to 0.3 dB.
Transmission lines and waveguides. The discussion concludes in next month's column, which will concentrate on other microwave components and terminology.

**new VHF records**

For some time now EME activity on 6 meters has been limited to a few energetic Amateurs who "think big". That is rapidly changing. I just heard that there is a new 6-meter EME DX record. On November 15, 1987 Ray Rector, WA4NJP, (EMB4) worked Jim Treybig, W6JKV, (CM87) for an approximate distance of 2145 miles (3451 km). I hope to have more details in next month's column. Congratulations, Ray and Jim.

**important VHF/UHF events:**

- **March 16**: EME perigee
- **March 18**: New moon (eclipse of the sun)
- **March 21**: ± 2 weeks. Optimum time for propagation
- **April 11**: ARRL 144 MHz Spring Sprint Contest (Monday evening local)
- **April 13**: EME perigee
- **April 16**: New moon
- **April 19**: ARRL 220 MHz Spring Sprint Contest (Tuesday evening local)
- **April 21**: Predicted peak of the Lyrids meteor shower at 1730 UTC
- **April 27**: ARRL 432 MHz Spring Sprint Contest (Wednesday evening local)
- **April 29-30**: Dayton Hamvention
- **May 1**: Dayton Hamvention

**references**


A right-angle bend is another common waveguide transition. An abrupt bend can be lossy, so smoothly bent waveguides (fig. 5B) or an abrupt bend with a mitered corner (fig. 5C) are used.

Sometimes it is desirable to connect a coaxial device to a waveguide section and vice versa. It is referred to as a coax-to-waveguide transition using a voltage probe.

**summary**

This month's topic was microwave
the ultimate antipode DX

In our eternal search for the optimum propagation path and mode, one in particular — antipodal DX — has probably escaped our attention. The antipode is the farthest location on the earth from you. You can visualize this point by drawing a line from your location through the center of the earth to the opposite side of the world, or calculate it by taking the opposite latitude (40°S from 40°N) and subtract your longitude from 180° and switch west to east or vice versa. Now the question is: are any Radio Amateurs there?

what’s special about your antipode?

All directions point to it, every great circle path from your location goes through it, and, at the antipode there are energy focusing effects enhancing signal strengths. Experiments have determined that the antipode reception area has a 300-mile radius before the signal diminishes by 12 dB. At greater distances, signal levels rebuild by 6 dB. This 6-dB range is equivalent to the cyclical signal variations that occur in propagation mode changes. The 6-dB circle perimeter is not fixed and its size can vary on a short (diurnal) and long term (yearly) basis much like any other geophysical parameter. Propagation experiments also show that reception occurs up to 50 percent more often at the antipode than at a location only 900 miles away. The operating frequency used must not exceed the MUF for the particular azimuth you choose. Avoid paths requiring the signal to cross the polar regions because of accompanying low MUFs, geomagnetic, and auroral signal absorption problems. Also avoid equatorial paths where the MUF is considerably higher than the operating frequency because the greatest daytime signal absorption is found in those directions. Just remember — many directions still point toward your antipode and one will be best for you.

last-minute forecast

The higher hf bands should peak (higher MUF) during the third and fourth weeks of March with increased solar flux levels and flare activity. These flares may cause geomagnetic field-ionospheric disturbances around the 17th and 26th. The solar wind particle count is expected to increase around the 6th as a result of thinner solar coronal. Excellent transequatorial openings should accompany these disturbances. Lower solar flux values expected during the first two weeks of the month with lower signal absorption will enhance daytime lower band DX (though not as good as a year ago). Evening/nighttime DX should be good except when local thunderstorm noise increases. Spring equinox occurs on March 20th at 0939 UTC. A full moon appears on the 3rd and will be at perigee on the 16th.

band-by-band summary

Ten, fifteen, and twenty meters will be open from morning to early evening almost daily in most areas of the world. Expect higher band openings to be shorter and closer to local noon. Transequatorial propagation on these
| MARCH | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| ASIA  | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| FAR EAST | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| EUROPE | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| S. AFRICA | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| S. AMERICA | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| ANTARCTICA | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| NEW ZEALAND | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| OCEANIA | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| AUSTRALIA | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |
| JAPAN | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 0000 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 |

The italicized numbers signify the bands to try during the transition and early morning hours, while the standard type provides MUF during "normal" hours.

*Look at next higher band for possible openings.

March 1988
**magnetic mount antennas**

Hustler, Inc. announces two new magnetic mount antennas. Rated at 100 watts, the RX series consists of a 5:8 wave, 3.4-dB antenna. The RX-2 B20 (2200 MHz) and the RX-220 (220 MHz) are chrome with a black mount and coil cover. The suggested list price for both models is $24.95. The RX series is available in all black versions (models RX-2B and RX-220B), each with a list price of $24.95.

The FX series, rated at 200 watts, is a 5:8 wave, 3.44-dB antenna on a heavy-duty magnet mount which holds at speeds of 75 mph. The FX-2 (2 meter) and the FX-220 (220 MHz) are chrome with a black mount and coil cover. The suggested list price for both models is $19.95. The RX series is available in all black versions (models RX-2B and RX-220B), each with a list price of $24.95.

The FX series, rated at 200 watts, is a 5:8 wave, 3.4-dB antenna on a heavy-duty magnet mount which holds at speeds of 100 mph. The FX-2 (2 meter) and the FX-220 (220 MHz) list for $24.96 each. All black versions of the FX series are available as models FX-2B and FX220B priced at $29.95 each.

For information contact Hustler, Inc., One New-Tronics Place, Mineral Wells, Texas 76067.

Circle 301 on Reader Service Card.

**high-power linear amplifier**

The HL 180V is a high-power linear amplifier designed for 144-MHz band and all-mode operation. It provides a maximum output power of 170 watts. You can operate the amplifier with 3/10/25 watt output transceivers, as it will automatically select the incoming drive level. The LED power level indicator enables you to monitor the output power level at all times. Over-voltage protection circuit prevents the RF power transistors from being damaged. Remote control lead wires are incorporated to enable a smooth and instant changeover especially on SSB.

The THL model HL 180V is now available at your local ENCOMM dealer. Suggested list price is $359.95. For further information contact ENCOMM, Inc., 1506 Capital Avenue, Plano, Texas 75074.

Circle 302 on Reader Service Card.

**MFJ speaker/mic for handhelds**

The new MFJ speaker/mic with its lapel/pocket clip, lets you carry your handheld easily. It has a lightweight retractable cord and a connector that fits ICOM and Yaesu handhelds. It features clear audio on both transmit and receive.

Available from MFJ dealers or direct from the company, the MFJ-284 retails for $24.95 and has a one-year unconditional warranty.

For more information contact MFJ Enterprises, Inc., P.O. Box 494, Mississippi State, Mississippi 33752.

Circle 303 on Reader Service Card.

**novice welcome**

Gordon West Radio School has a Novice welcome package containing literature sheets, rebate coupons, and in-store discount offers from 30 Amateur Radio equipment manufacturers and accessory suppliers, and five dealers.

Included are ICOM, Kenwood, and Yaesu gift certificates worth up to $25 each towards the purchase of new radio gear and free magazine issue certificates with subscription discounts. There are catalogs from Amateur Radio accessory manufacturers and "tip sheets" from manufacturers on how to set up a beginner Novice voice class station sent with each beginner course.

The 21-day Novice course includes two stereo code-learning cassettes and West’s 112-page Novice book. Prized at $19.95 (plus $2.50 postage and handling), the course materials include: FCC Form 610, a frequency reference chart, laminated world map, and a sample Novice exam package.

Students who pass any upgrade examination or Novice entry-level exam receive equipment discount coupons from ICOM, Yaesu, and Kenwood. Anyone who passes the exams within 120 days, using our materials, may write and receive radio rebate rewards, an FCC license holder, certificate of course completion, certificate for a free Amateur Radio magazine, and other coupons.

For more information, write to Gordon West Radio School, 214 College Drive, Costa Mesa, California 76067.

Circle 304 on Reader Service Card.

**Heathkit catalog**

The Heathkit H-386 Desktop Computer, an 80386-based computer that operates two to three times faster than a PC/AT, appears in the latest Heathkit Catalog. Also featured is the Zenith Data Systems Flat Tension Mask Color Monitor with a flat screen and VGA compatibility.

The most powerful kit computer offered today, the H-386 provides graphics capabilities using a 31-kHz video card that automatically emulates EGA, CGA, MDA, and Hercules graphics, depending on what video mode software requires. The standard 1 megabyte of RAM can be expanded up to 16 megabytes. The kit is easy to build and includes the H-386 with a 1 megabyte of RAM, the VGA video card, and one 1.2 megabyte 5-1/4 inch disk drive for $3349.95.
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The 1988 call directory includes listings for amateur radio enthusiasts, providing contact information for various organizations and businesses.
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COMING EVENTS

Pennsylvania:
March 5: The annual Armstrong Radio Club's hamfest at Crestview Country Club, Crestview, PA. (information not available)

Massachusetts:
March 6: The Mount Tom Amateur Radio Association's annual hamfest at the Franklin Community Center, Franklin, MA. (information not available)

New Jersey:
March 11: The Amateur Radio Club of East Orange's annual hamfest at the Parish of the Holy Name, East Orange, NJ. (information not available)

Massachusetts:
March 17: The annual hamfest at the Metroplex Convention Center, Metroplex, MA. Information not available.

NEW HAMPSHIRE:
March 19: The New Hampshire Hamvention at the Hillsboro International Airport, Hillsboro, NH. Information not available.

TEXAS:
March 20: The annual AMTA convention at the Sangean Radio Convention in Dallas, TX. Information not available.

Florida:
March 20: The annual Florida Open House event at the Florida Open House, Inc, in Pinellas Park, FL. Information not available.

ARIZONA:
March 22: The annual Arizona Hamvention at the Prescott Amatuer Radio Club, Prescott, AZ. Information not available.

MINNESOTA:
March 22: The annual Minnesota Hamvention at the Hennepin County Fairgrounds, Chaska, MN. Information not available.

MICHIGAN:
March 23: The annual Michigan Hamvention at the Dearborn Convention Center, Dearborn, MI. Information not available.

WASHINGTON:
March 23: The annual Seattle Hamvention at the CenturyLink Field, Seattle, WA. Information not available.

OREGON:
March 23: The annual Portland Hamvention at the Portland Expo Center, Portland, OR. Information not available.

IDAHO:
March 23: The annual Idaho Hamvention at the Boise Convention Center, Boise, ID. Information not available.

WASHINGTON:
March 23: The annual Seattle Hamvention at the CenturyLink Field, Seattle, WA. Information not available.
flea market

Market: Saturday 9 a.m. - 2 p.m.
Location: The market is held at the Ballston Spa Community Center, located at 241 N. Main St., Ballston Spa. For more information, call 518-888-8220 or visit www.fleamarketballstonspa.com.

HAM EXAMS: The MIT L.H. Riemer Repeater Association and the MIT Radio Society offer monthly Ham Exams. All classes will be held at the MIT Radio Society, located at 2501 Massachusetts Ave., Cambridge, MA 02139. Exam times will be announced in the MIT Radio Society newsletter. For more information, call 617-253-4848 or visit www.mitradio.org.

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March 1988
transmission lines

Transmission lines are a vital part of any Amateur station, but often the most mysterious component (and most misunderstood as well) used in setting up a station. This month’s notebook looks at how transmission lines are put together and what they do. Perhaps you’ll feel a bit more at ease in a discussion of lines and their advantages and faults after reading it.

why a transmission line?

There was a time when transmission lines were not widely used by Amateurs — when TV didn’t exist, houses (and neighbors) were not packed together on postage stamp sized lots, and those who happened to hear an Amateur on their Broadcast-Band sets were more interested in eavesdropping than complaining.

In the interest of simplicity and economy, the end of a length of wire was simply run into the ham shack and tapped onto the power amplifier plate tuning circuit through a suitable capacitor. The tap was moved along the turns of the coil until the proper plate current at resonance was obtained, indicating that the amplifier was properly loaded and providing power to the antenna.

This worked well — the antenna radiated (and the radiation included several harmonics as well as the fundamental signal), OSOs were made, and everyone was happy. The fact that all of the wire radiated — even the portion that was inside the ham shack — didn’t particularly bother anyone. An occasional “hot” key or microphone gave a slight tingle or warm sensation to the operator, and sometimes the lights flickered a bit from induced rf in the power lines, but that was part of the mystique of being an Amateur.

Those who were more interested in doing things right knew they would get better results by placing the antenna high, away from power lines, telephone lines, and other metal objects that could intercept the energy being sent toward the horizon for a distant station to hear. What was needed was a means of getting the energy across that gap between the output of the transmitter in the shack and the feed-point of the antenna many feet in the air. The answer was a transmission line.

Early transmission lines were hand-made, open-wire lines with fairly wide spacing (often 6 or 8 inches between wires). The ingenuity of hams in adapting materials for use as insulating spacers was just as great then as it is now: glass rods, porcelain insulators, and wood dowels that had been boiled in paraffin (wax) were common materials. Today, almost any type of transmission line you need can be found at electronics parts stores or Amateur conventions and flea markets. Still, there are those who take pride in constructing an open-wire line of parallel No. 14 wire supported by plastic hair curlers or 35-mm film can lids.

open-wire lines

Figure 1A shows the evolution of a single-wire antenna (or feeder for an occasional “hot” key or microphone gave a slight tingle or warm sensation to the operator, and sometimes the lights flickered a bit from induced rf in the power lines, but that was part of the mystique of being an Amateur.

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PARALLEL WIRE LINE

fig. 2. The impedance of open-line (parallel wire) transmission line is determined by the center-to-center spacing of the wires and its diameter. Any material between the wires other than air will lower the impedance.

COAXIAL LINE

fig. 3. Coaxial cable impedance is determined by the diameter of the center conductor, the inside diameter of the outer conductor, and the distance and dielectric between them.

end-fed long wire) into a parallel-wire transmission line (fig. 1B). The line works because the fields from instantaneous current flow cancel each other. This means that the line does not radiate any significant amount of energy from your transmitter; it is being passed along to the antenna where it is radiated into space well above wires, TV sets, and telephones.

All transmission lines have a characteristic impedance, referred to as ‘Z’, or ‘Z0’. This is important because all parts of the system must be matched, as discussed in last month’s notebook. The impedance of a line is determined by the diameter of the wires and the space between them, as shown in fig. 2. The formula given is accurate for wires that have mostly air between them — a few supporting spacers will not change the impedance enough to worry about. The air between the wires is called the ‘dielectric’, just as it is when referring to air between the plates of a capacitor.

Any insulating material other than air, if present in large amounts, will significantly change the impedance of the line — usually to a lower value. If you measure the wire diameter and spacing of common 300-ohm TV twin lead, and use the impedance formula in fig. 2, you’ll get the wrong answer. The manufacturer knows what the effect of his dielectric is, and adjusts the spacing of the wires accordingly.

Two types of open-wire lines are 450- and 300-ohm “ladder line”, once widely used for low-loss TV reception. This is the lowest loss transmission line you can get for an Amateur hf band installation and requires some care when putting it to use. Sharp bends are a no-no, and it should not be closer than 6 or 8 inches to any metal: gutter pipes, eaves, aluminum siding, window frames, or other wires. It should be stretched tight and supported on insulators so it will not swing in the wind or twist and short-circuit.

Open-wire lines need a matching device or transformer of some sort between the line and the transmitter (and sometimes between the line and the antenna). For transforming from coaxial cable to open-wire line, a balun is often used. This device gets its name from the operation it performs — adapting a balanced line to an unbalanced one. The function of a balun is merely this — it does not match impedances.

There are different types of baluns: 50-to-300 ohm, 50-to-50 ohm, and 75-to-300 ohm are the most common. A typical installation might require a 50- or 75-ohm transmitter output to be adapted to 300-ohm open-wire line; a 75-to-300 ohm balun will do the job. Another typical use is at the center of a half-wave dipole for 80 meters — a 50-to-50 ohm balun is sold for this purpose, enclosed in a weather-tight case, ready to connect between the coaxial cable and the antenna wire.

Table 1. Characteristics of commonly used transmission lines.

<table>
<thead>
<tr>
<th>Line</th>
<th>Z0 ohms</th>
<th>Velocity factor</th>
<th>Outside diameter</th>
<th>Maximum working voltage (rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RG-8X</td>
<td>52.0</td>
<td>75</td>
<td>0.242</td>
<td>-</td>
</tr>
<tr>
<td>RG-8/U</td>
<td>52.0</td>
<td>66</td>
<td>0.405</td>
<td>4000</td>
</tr>
<tr>
<td>RG-8/U foam</td>
<td>50.0</td>
<td>80</td>
<td>0.405</td>
<td>1500</td>
</tr>
<tr>
<td>RG 8A/U</td>
<td>52.0</td>
<td>66</td>
<td>0.405</td>
<td>5000</td>
</tr>
<tr>
<td>RG-9A/U</td>
<td>51.0</td>
<td>66</td>
<td>0.420</td>
<td>4000</td>
</tr>
<tr>
<td>RG 9B/U</td>
<td>50.0</td>
<td>66</td>
<td>0.420</td>
<td>5000</td>
</tr>
<tr>
<td>RG 11/U</td>
<td>75.0</td>
<td>66</td>
<td>0.405</td>
<td>4000</td>
</tr>
<tr>
<td>RG-11/U foam</td>
<td>75.0</td>
<td>80</td>
<td>0.495</td>
<td>1600</td>
</tr>
<tr>
<td>RG-17A/U</td>
<td>75.0</td>
<td>66</td>
<td>0.870</td>
<td>11,000</td>
</tr>
<tr>
<td>RG 58/U foam</td>
<td>53.5</td>
<td>79</td>
<td>0.195</td>
<td>600</td>
</tr>
<tr>
<td>RG-58A/U</td>
<td>53.5</td>
<td>66</td>
<td>0.195</td>
<td>1900</td>
</tr>
<tr>
<td>RG-59/U foam</td>
<td>75.0</td>
<td>79</td>
<td>0.242</td>
<td>800</td>
</tr>
<tr>
<td>RG-59A/U</td>
<td>73.0</td>
<td>66</td>
<td>0.242</td>
<td>2300</td>
</tr>
</tbody>
</table>

Aluminum Jacket, foam (hardline)

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Z0 ohms</th>
<th>79</th>
<th>0.875</th>
<th>79</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 inch</td>
<td>50.0</td>
<td>81</td>
<td>0.5</td>
<td>2500</td>
</tr>
<tr>
<td>7/8 inch</td>
<td>90.0</td>
<td>81</td>
<td>0.875</td>
<td>4500</td>
</tr>
<tr>
<td>1/2 inch</td>
<td>75.0</td>
<td>81</td>
<td>0.5</td>
<td>2500</td>
</tr>
<tr>
<td>7/8 inch</td>
<td>75.0</td>
<td>81</td>
<td>0.875</td>
<td>4000</td>
</tr>
</tbody>
</table>

open wire

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Z0 ohms</th>
<th>79</th>
<th>0.875</th>
<th>79</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV 1/2 inch</td>
<td>300</td>
<td>95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 inch</td>
<td>450</td>
<td>95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 ohm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>twin lead</td>
<td>300</td>
<td>80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
You can perform impedance matching with open-wire lines by using a matching network, like the Transmatch or similar circuit that accepts the line impedance at one input and the transmitter impedance at the other. At the antenna, matching methods include a quarter-wave transformer (that is the mean impedance between the antenna and the line), matching stubs, hairpin loops, or a specially designed balun.

coaxial lines

The principles that apply to open- or parallel-wire transmission lines also apply, with some modifications, to coaxial lines. Figure 3 shows how the impedance of an air-dielectric coaxial line is determined. Keep the conductors from touching each other (and maintain constant spacing), and remember that the insulating material used for support affects the impedance. One thing that is critical with coaxial cable is the power level it can handle. The center conductor is surrounded by insulation, and any heat generated by current flow in the copper is trapped inside the cable. If the heat is great enough the insulation can melt or break down and create a short-circuit. This is usually not a problem at legal Novice power levels, but at higher levels and high SWR, RG-58 and RG-8 cables have been known to burst into flame. Table 1 shows some important characteristics of a few common transmission lines, including the rms voltage they can withstand.

Be wary of “bargain” transmission lines found at flea markets and surplus houses. These coaxial cables can differ in several ways from what you might buy from a dealer. Only two are serious enough to create problems: the amount of shielding provided by the outer conductor, and possible contamination of the dielectric.

Most coaxial cables used today are flexible; that is, they are constructed with a woven braid as the outer conductor which allows the cable to bend in a reasonable curve without damage. While it is impossible to obtain 100 percent coverage with a braid, some cables come very close (better than 90 percent). It takes only a moment to remove a small piece of outer jacket from coax and look at the amount of visible braid. If the weave is loose, and you can see a lot of dielectric peeking through, the cable is no bargain at any price. Poor coverage lets rf “leak” out and noise leak in. The impedance is not likely to be constant, and losses will be greater than with good cable. Cables with double braid covering can sometimes be found, and these are excellent, although you may have trouble getting both braids to fit into a connector.

Another “gotcha” is contamination of the dielectric. Moisture and gases can be absorbed by almost any plastic, and the dielectric material itself can change chemically because of sunlight and heat. This changes the characteristic impedance of the line, increases loss, and may lead to heating and breakdown of the line at higher power levels. Some cables resist contamination, and are worth looking for if you live in a particularly hot, damp, or smoggy area. Some can even be left lying on the ground or buried without danger of contamination, but should be tested for losses every year or so. Decibel Products VB-8 and Times Wire and Cable Impervion are two.

other impedance

The cable television industry uses 75 ohms as its standard for cable and amplifier termination. Surplus cable, often

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MODEL PT2500A LINEAR AMPLIFIER
The Barker & Williamson PT2500A Linear Amplifier is a completely self-contained Table Top unit designed for continuous SSB, CW, RTTY, AM or ATV operation. It is used for coverage of all amateur bands between 1.8 MHz and 21 MHz. It can be easily modified for frequencies outside the amateur bands or for commercial or military application. Two type 3-500Z glass envelope tubes provide reliability and rapid turn-on time.

FEATURES INCLUDE:

- Full 1500 watt output
- PI-network input for maximum drive
- Pressurized piumium cooling system
- DC antenna relay for ham-free operation
- Illuminated SWR and power meters
- VSWR tuning for accurate settings
- PL output for greater harmonic attenuation

Buckedly constructed of proven design, this amplifier reflects the manufacturer's critical attention to details such as the silver-plated tank coil for maximum efficiency. Cathode zero is tuned and internal/external cooling are among the protective and safety devices employed. Input and output impedances are 50 ohms.

Dimensions: 17" wide x 19" deep x 8½" high
Weight: 60 lbs (shipped in 3 cartons to meet UPS requirements)

Price: $2175.00 FOB factory. Price includes one year limited warranty. Call or write factory for complete specifications.

MODEL VS1500A ANTENNA COUPLER
The Barker & Williamson VS1500A antenna coupler is designed to match virtually any receiver or transmitter to any antenna. It is designed to cover the 160 to 10 meter range (1.8 to 30 MHz) with up to 1500 watts RF power to almost any antenna, including dipoles, inverted vee, verticals, mobile whips, beans, random wire and others. Used coax cable, balanced lines or a single wire. A 14 balun is built in for connection to balanced lines.

FEATURES INCLUDE:

- Series parallel capacitor connection for greater harmonic attenuation
- In-circuit wattmeter for continuous monitoring
- VSWR tuning for easy adjustment

Front panel switching allows rapid selection of antennas, or to an external dummy load, or permits bypassing the tuner.

Dimension (Approximate): 11" wide x 13" deep x 6½" high
Weight: 5 lbs

Price: $499.00 FOB factory. Fully warranted for one year.

89 March 1988
FREQUENCY COUNTERS
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Small enough to fit into a shirt pocket, our new 1.2 GHz and 1.3 GHz, 8 digit frequency counters are not toys! They can actually outperform units many times their size and price! Included are rechargeable Ni-Cad batteries installed inside the unit for hours of portable, cordless operation. The batteries are easily recharged using the AC adaptercharger supplied with the unit.

The excellent sensitivity of the 1200H makes it ideal for use with the telescoping RF pick-up antenna; accurately and easily measure transmit frequencies from handheld, fixed, or mobile radios such as: Police, firefighters, Ham, taxi, car telephone, aircraft, marine, etc. May be used for counter surveillance, locating hidden “bug” transmitters. Use with grid dip oscillator when designing and tuning antennas. May be used with a probe for measuring clock frequencies in computers, various digital circuitry or oscillators. Can be built into transmitters, signal generators and other devices to accurately monitor frequency.

The size, price and performance of these new instruments make them indispensable for technicians, engineers, schools, Hams, CBers, electronic hobbyists, short wave listeners, law enforcement personnel and many others.

STOCK NO:

#1200HKC Model 1200H in kit form, 1-1200 MHz counter complete including all parts, cabinet, Ni-Cad batteries, AC adapter-battery charger and instructions ........................................ $99.95

#1200HC Model 1200H factory assembled 1-1200 MHz counter, tested and calibrated, complete including Ni-Cad batteries and AC adapter/battery charger ........................................ $137.50

#1300HC Model 1300H factory assembled 1-1300 MHz counter, tested and calibrated, complete including Ni-Cad batteries and AC adapter/battery charger ........................................ $150.00

ACCESSORIES:

#TA-100S Telescoping RF pick-up antenna with BNC connector ................... $12.00

#P-100 Probe, direct connection 50 ohm, BNC connector ................... $18.00

#CC-70 Carrying case, black vinyl with zipper opening. Will hold a counter and accessories ................... $10.00

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"They said I couldn't work DX with just 100 watts. Especially with a radio that has less than 1000 switches on the front panel.

But the truth is, I'm working lots of DX, more than some of these blockbuster types, thanks to my Yaesu FT-747GX.

You see, my no-nonsense FT-747GX was designed with me in mind, so I can hop around the band fast to nail those DX stations. While the other guys are warming up their amplifiers, I'm working the new country!

My FT-747GX has a super receiver, with a directly-driven mixer for great overload protection. And, Yaesu included the CW filter in the purchase price (I used the money I saved on postage for the QSL cards!).

And my FT747GX is loaded with other features. The receiver works from 100 kHz straight through to 30 MHz, and it's a fantastic shortwave broadcast receiver. I can use all twenty memories for that alone! Plus it's got dual VFOs. A noise blanker. Split frequency operation for the pile-ups. And scanning up the band helps me check out openings as they happen.

I just put in the optional crystal oven, and next month I'm going to pick up the FM board. I can't wait to tell my buddies I worked England on a repeater!

And with the money I saved when I bought my FT747GX, I got a second ten-meter antenna for satellite work on the high end of the band. I use my personal computer to tell me what satellites are going by, and the computer even sets the frequencies on the radio for me.

Now my friends are getting FT747GX rigs, too. I knew they'd figure out my secret weapon sooner or later. But now I'm setting the pace!

Thanks, Yaesu. You've made a rig that makes sense."

Yaesu USA 1220 Edwards Road, Cerritos, CA 90701 (213) 404-2700. Repair Service: (213) 404-4884. Parts: (213) 404-4847. Prices and specifications subject to change without notice.

"They laughed when they saw my radio. Then they saw my logbook."
KS-940S

Competition class HF transceiver

TS-940S - the standard of performance by which all other transceivers are judged. Pushing the state-of-the-art in HF transceiver design and construction, no one has been able to match the TS-940S in performance, value and reliability. The product reviews glow with superlatives, and the field-proven performance shows that the TS-940S is "The Number One Rated HF Transceiver!"

- 100% duty cycle transmitter
- Kenwood specifies transmit duty cycle time. The TS-940S is guaranteed to operate at full power output for periods exceeding one hour. (14.250 MHz, CW, 110 watts.) Perfect for RTTY, SSTV, and other long duration modes.
- First with a full one-year limited warranty.
- Extremely stable phase locked loop (PLL) VFO. Reference frequency accuracy is measured in parts per million!

Optional accessories:
- All-940 full range (160-10m) automatic antenna tuner
- SP-940 external speaker with audio filtering
- YG-45SC-1 (600 Hz), YG-455CN-1 (250 Hz), YG. 98C-1 (500 Hz) CW filters
- YK-88A (116 kHz) AM filter
- VS 1 voice synthesizer
- 51.1 temperature compensated crystal oscillator
- MC-435 UP/DOWN hand mic
- MC-60A, MC-80, MC-85 deluxe base station mics
- PC-IA phone patch
- TL-922A linear amplifier
- SM-220 station monitor
- BS-8 panel display
- SW-200A and SW-2000 SWR and power meters
- IF-232C/IF-10B computer interface

- Complete all band, all mode transceiver with general coverage receiver. Receiver covers 150 kHz-30 MHz. All modes built-in: AM, FM, CW, FSK. LSB, USB.
- Superb, human engineered front panel layout for the DX-minded or contesting ham. Large fluorescent tube main display with dimmer, direct keyboard input of frequency, flywheel type main tuning knob with optical encoder mechanism all combine to make the TS-940S a joy to operate.
- One-touch frequency check (T-F SET) during split operations.
- Unique LCD sub display indicates VFO, graphic indication of VBT and SSB Slope tuning, and time.
- Simple one step mode changing with CW announcement.
- Other vital operating functions. Selectable semi or full break-in CW (QSK). RTXIT all mode squelch. RF attenuator. Select switch. Selectable AGC. CW variable pitch control, speech processor, and RF power output control. Programmable band scan or 40 channel memory scan.

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