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MARCH 1989

ARRL Experimenters' Exchange and AMSAT Satellite Journal

ACE--a Promising New Satellite Orbit

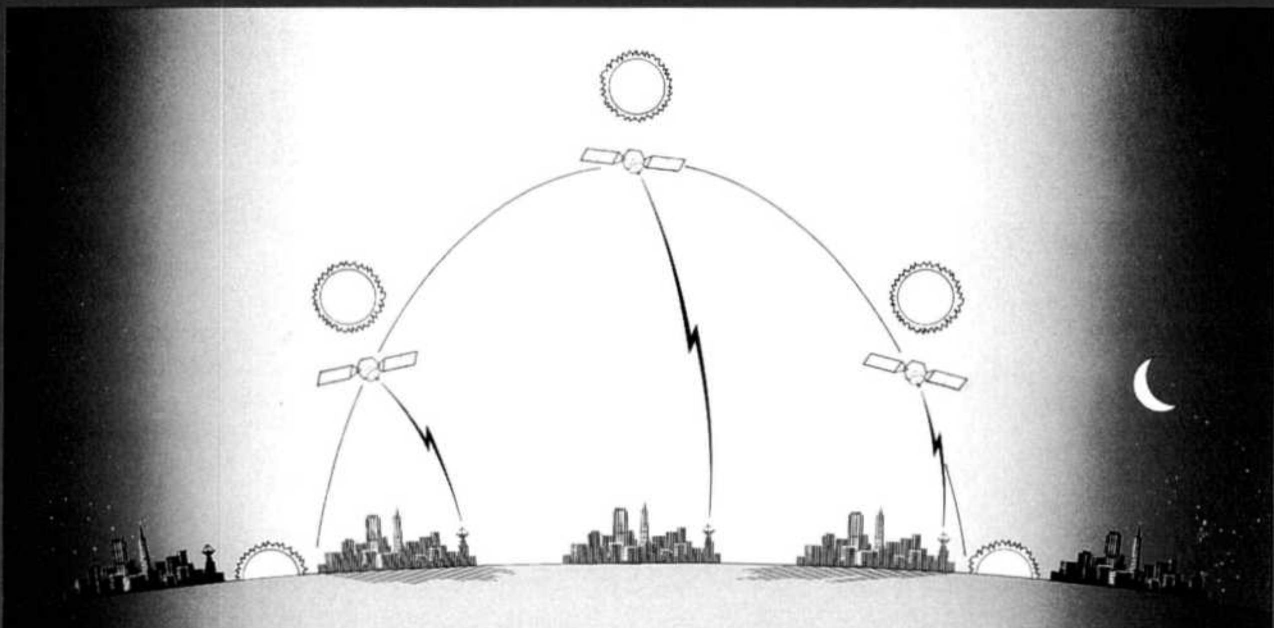

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TABLE OF CONTENTS

COLUMNS

ABOUT THE COVER

The ACE (Apogee at Constant time of day Equatorial) orbit has several advantages over the Molniya orbit used for amateur Phase III satellites. For one thing, spacecraft apogee occurs (as its name implies) at the same time each day, greatly simplifying tracking. Cover illustration by Ernest D. Polo and Carlos Renowitzky.

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1) provide a medium for the exchange of ideas and information between Amateur Radio experimenters
2) document advanced technical work in the Amateur Radio field
3) support efforts to advance the state of the Amateur Radio art.

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

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Empirically Speaking. . .

AMSAT Spins Off Technology

For several years, AMSAT-NA has been puzzling over how to fund future space projects such as Phase 4 (geostationary satellites). While low-earth-orbit and highly elliptical-orbit communications satellites have cost AMSAT up to a few hundred thousand dollars each, Phase 4 costs would run perhaps ten times that. Where does one find money an order of magnitude greater than previous organizational experience? Could the membership contribute enough? Probably only a fraction. Are there any sugar daddies with $3-4,000,000 to spend on such a project? Rather unlikely, more likely only another fraction.

In the commercial and government satellite worlds, small satellites became the watchword, and the race was on for US Government SDI and other R&D money by the satellite manufacturers. Hmmm. Since AMSAT had plenty of experience building small satellites and the commercial companies were geared up for large satellites, could it be that AMSAT might have some know-how to sell?

Certainly. But how? There has been what seems like nonstop debate within the AMSAT-NA hierarchy on this topic for more than a year. Would it be necessary to set up a wholly owned, for-profit subsidiary to handle this technology spin-off? Where would the seed money come from? If it came from the AMSAT-NA treasury, would that dry up money for membership services? What would happen if AMSAT-NA threw a subsidiary and nobody came?

Another sticky wicket was intellectual property. There has been a general willingness among Amateur Radio designers and programmers to make the fruits of their labors available to amateur organizations, such as AMSAT, and hams in general at no cost (or perhaps just out-of-pocket expenses). But when it comes to someone making a buck off their ideas, they typically want a piece of the action. So, what happens if you designed/invented some "superwidget" and with abandon donated it to the Amateur Radio organization that integrated it into a project? Who owns it? If the individual did some part and others contributed others or gave the individual half an idea, how do you split the pie and reconcile all the other interests? It seems you just keep stirring the pot, talking to companies and praying for a miracle.

Finally, it paid off. On February 5, 1989, AMSAT-NA president Doug Loughmiller, KO5I, announced the inking of an exclusive agreement for the commercial use of certain Microsat technology with Interferometrics, Incorporated of Vienna, Virginia. Under the agreement, Interferometrics will market and produce microsats for non-Amateur Radio applications and will pay AMSAT-NA a fee based upon the revenue it receives from this program. Revenues thus generated will be used for amateur satellite construction and related technical projects. Principal responsibility for implementing this agreement rests with AMSAT-NA Chairman of the Board and Vice President-Engineering Jan King, W3GEY.

No money has changed hands yet. Loughmiller emphasizes that the existence of the agreement does not lessen the need for continuing AMSAT-NA funding from other sources. Look for the unfolding story on this relationship in the new *AMSAT Newsletter*.

Meanwhile, the crafting of the Microsats goes on. Telemail is alive with all the engineering details exchanged between designers. In the ARRL laboratory, Jon Bloom, KE3Z, and Bruce Hale, KB1MW, are finishing up the Battery Charge Regulator (BCR) module printed-circuit boards. Selection of components for these boards has involved countless hours of thermal qualification using the lab's temperature chamber. The transmitter, receiver, CPU and other modules are being developed elsewhere. Some of the many people involved include: Tom Clark, W3IWI, Dick Daniels, W4PUJ, Gordon Hardman, KE3D, Matjaz Vidmar, YT3MV, Lyle Johnson, WA7GXD, Eric Gustafson, N7CL, Dick Jansson, WD4FAB, and Weber State College, Center for Aerospace Technology. —*W4RI*

MMICs Mimic Mixer

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Diode balanced mixers, long the favored circuit for heterodyne downconversion in RF receivers, suffer from two drawbacks: conversion loss, and the need for relatively high local-oscillator (LO) injection levels. The active balanced mixer circuit presented here uses two inexpensive monolithic microwave integrated circuits (MMICs) to afford significant conversion gain, and low noise figure, and requires extremely low LO drive levels.

The Mixer As A Nonlinear Element

The typical passive balanced mixer consists of three segments, as shown in Fig 1. The coupler is used to apply components of the RF input and LO signals to the nonlinear element, in a desired amplitude and phase relationship. It may consist of transmission-line delay networks, resistive or reactive power dividers, balun transformers, coaxial or waveguide directional couplers, hybrid couplers, or some combination of these. The coupler may be implemented with lumped constants, coaxially, with toroidal transformers, in stripline, or in microstripline form.

It is in the nonlinear network, typically comprised of Schottky barrier diodes, that sums and differences of the LO- and RF-input signals are generated. Diodes also generate harmonics, which in turn are responsible for the intermodulation products that often plague frequency conversion. Because diodes are passive, rather than active devices, their use also results in a signal amplitude loss in the conversion process. This familiar conversion loss also degrades system noise performance.

Because conversion only occurs when the diodes are forward biased to the knee of their response curve (remember, mixing is a nonlinear function, and thus requires a nonlinear response), a substantial amount of LO injection is necessary. This can be augmented by a dc bias for those mixers operating in "starved LO" mode, but doing so reduces the mixer's spurious-free dynamic range.

The IF matching network often provides two functions: It is responsible for transforming the diode network's output to the desired system impedance, as well as filtering from the IF the unwanted products of the input-signal and LO frequencies that have been passed along in the conversion process.

Consider Active Mixing

An active balanced mixer can borrow the basic topology of the familiar passive mixer, by substituting one or more RF active devices for the diode array. Nonlinear gain stages will affect not only the RF input signal (substituting conversion gain for the passive-mixer loss), but the LO signal as well, significantly reducing LO injection requirements. An additional advantage is that the noise performance of the active devices used can essentially establish system noise figure, often negating the need for preamplifiers ahead of the mixer.

One problem is that the nonlinear network must remain just that—nonlinear—for frequency conversion to occur. Past attempts to employ class-A preamp stages in balanced mixers[1] have met with only limited success, because excellent linearity (generally a requirement for preamplifiers) severely limits conversion efficiency.

MMIC gain stages are now available at low cost, and their application requires a minimum of external components. However, they are generally biased in class A. In fact, high linearity is one of their major selling points. In order to employ MMIC amplifiers for frequency conversion, it is necessary to bias them closer to cutoff.

Coupler Selection Considerations

A previous study[2] evaluated the suitability of several hybrid coupler topologies for use in passive balanced mixers. Four different couplers, each realizable in microstripline form, were considered (see Fig 2 and Table 1). In attempting to trade off four mutually exclusive parameters (SWR, amplitude imbalance, isolation, and insertion loss), the 1.5-wavelength hybrid ring coupler, or *rat-race*, was determined to be the most suitable alternative for passive mixer use. Because the same considerations of match, balance, isolation and loss apply equally to active-mixer design, I see no compelling argument against employing the same coupler topology in active balanced mixers.

Biasing The MMICs

Fig 3 shows a simplified equivalent circuit of the bias scheme typically used with MMICs. This is a version of modified collector feedback, which results in a relatively constant collector potential, somewhat independent of the applied potential or the value of the collector bias resistor, R_c. The combination of the dc source (V_{cc}) and the collector resistor (R_c) can

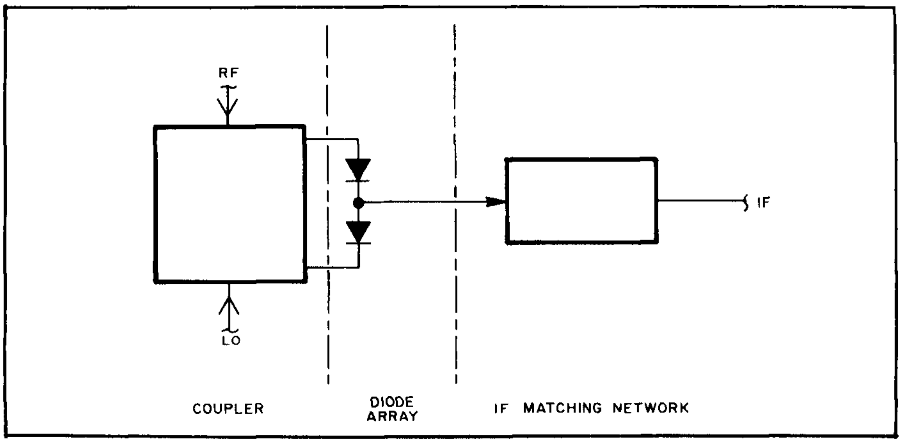


Fig 1—Block diagram of a passive balanced mixer.

[1]Notes appear on page 6.

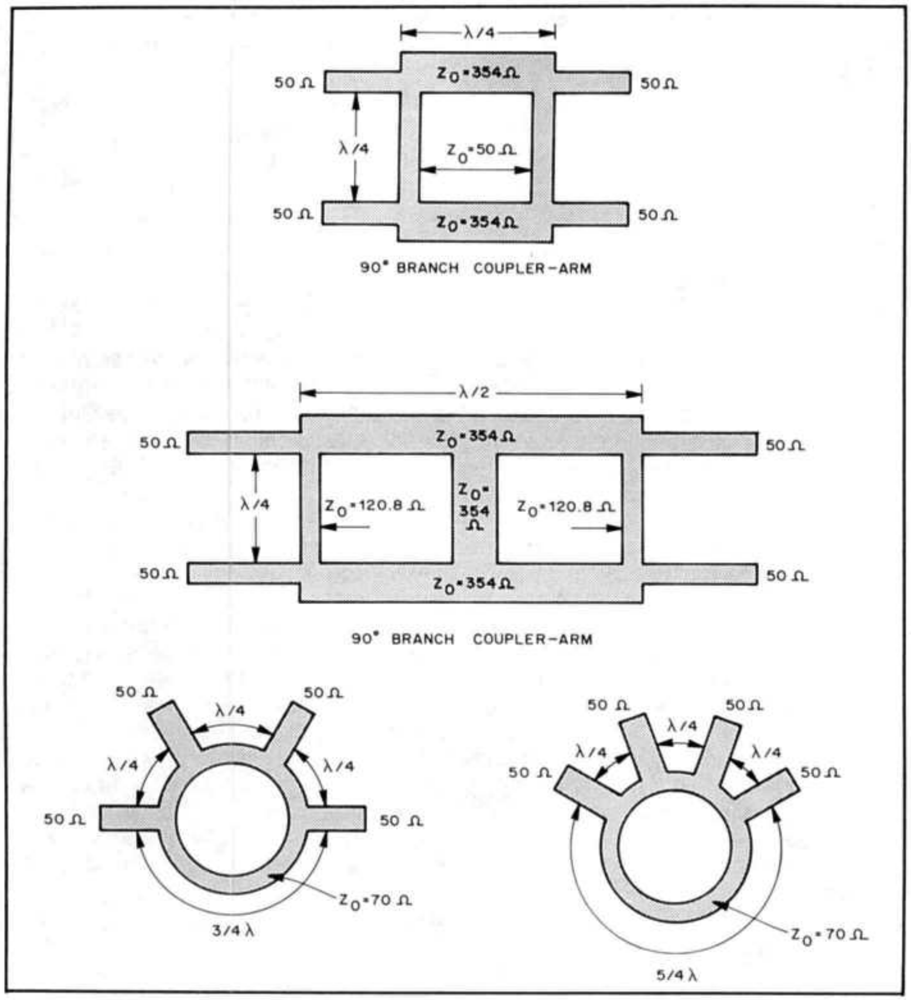


Fig 2—Four microwave hybrid couplers. See Table 1 for a performance comparison.

Table 1

Hybrid mixer performance comparison for a 20% bandwidth

Hybrid Type	*SWR*	*Amplitude Imbalance (dB)*	*Isolation (dB)*	*Relative Insertion Loss*
Two arm, 90° branch	1.45	0.7	14	1.0
Three arm, 90° branch	1.12	0.5	25.3	1.7
³⁄₂ λ, 180° ring	1.14	0.4	23.0	1.5
Extended, 180° ring	1.40	0.9	23.0	2.0

thus be thought of as a constant-current source, allowing easy control of the device's quiescent collector current.

I determined empirically that conversion efficiency is maximized at a quiescent current roughly half that recommended for linear amplification. For a single MMIC amplifier, then, mixing can be accomplished by roughly doubling the manufacturer's recommended bias-resistor value. As an added bonus, decreasing device current appears to somewhat lower the MMIC's internal noise figure.

For balanced mixer service, it's desirable to employ two identical MMIC amplifiers, which can be operated in dc parallel. Because their collectors are tied together to extract the IF component anyway, it's reasonable to drive both collectors with the bias resistance recommended for a single stage of amplification. This results in each MMIC being biased at half its accustomed current,

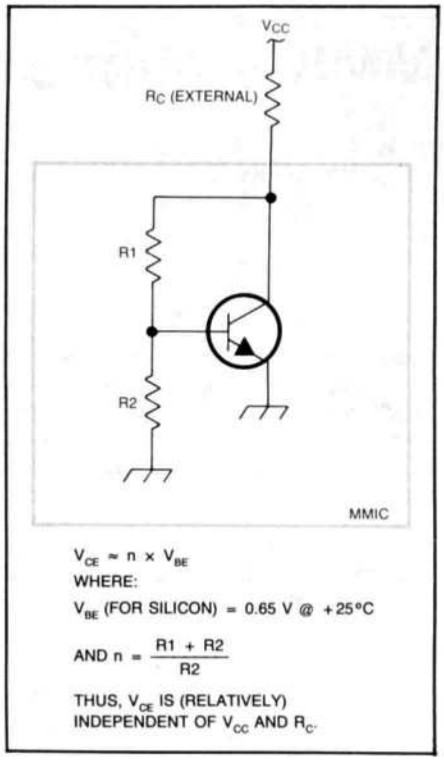


Fig 3—An example of MMIC biasing.

which places it in class AB, facilitating frequency conversion.

Assembling A Prototype Active Balanced Mixer

Some years ago, I developed a passive, diode balanced mixer for down-converting 1.7-GHz weather-satellite images to VHF.[3] The mixer used a ring hybrid coupler as described earlier, and because several etched circuit boards were left over from the project, I decided to assemble an MMIC active mixer on the same substrate. The schematic diagram of the mixer circuit is presented in Fig 4, and a photo of the mixer appears in Fig 5.

Hybrid coupler HY1 affords two paths between the RF input-signal (J1) and LO (J2) ports, which are 180° out of phase with each other. This affords the isolation between the RF input-signal and LO ports, which is characteristic of balanced mixers. Because the collectors of MMICs U1 and U2 are connected in parallel, their outputs are in phase. Hybrid HY1 applies the LO components from J2 to the inputs of the two MMICs 180° out of phase. Thus, though the MMICs amplify the LO signal (allowing low injection levels), the LO components at their outputs cancel, affording isolation between the LO and IF ports.

Because this design is a singly balanced mixer, there is no inherent isolation between the RF input-signal and IF ports. Note that hybrid HY1 applies the RF input-signal from J1 to the two MMIC

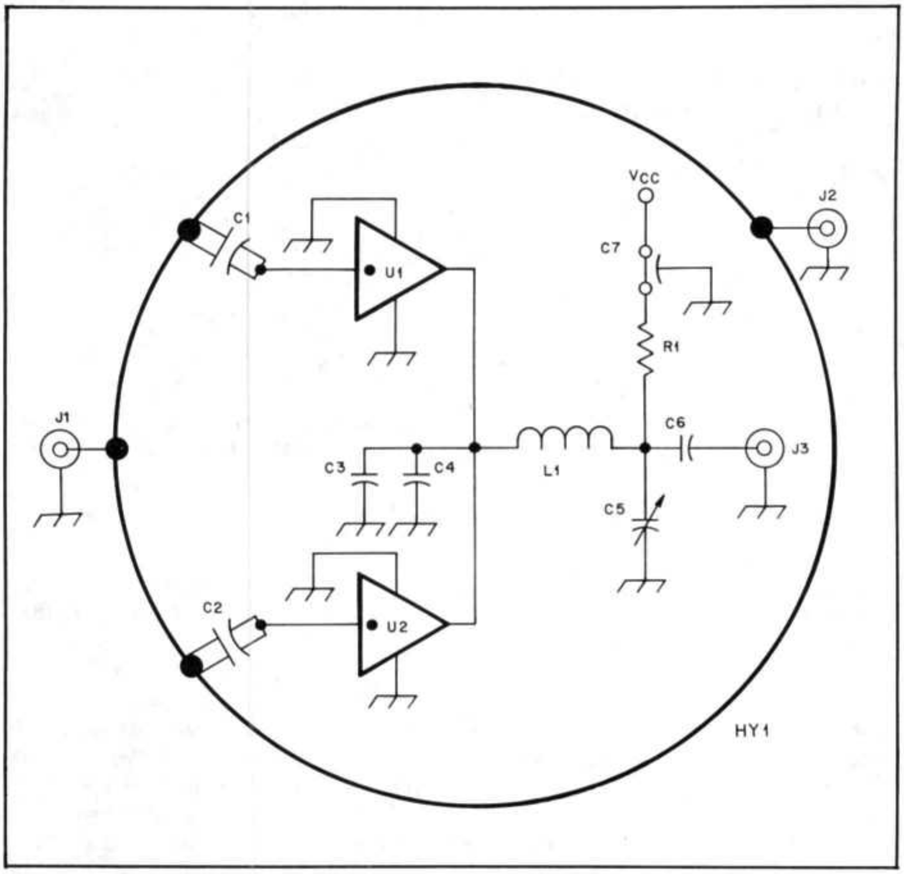


Fig 4—Schematic diagram of a prototype MMIC active balanced mixer.

HY1—540° ring hybrid; 70-Ω microstripline ring 1½ λ at operating frequency (see text).
J1, J2—SMA receptacle.
J3—BNC receptacle.
L1—0.01 μH.
C1,C2—50-pF chip capacitor.
C3—Etched bypass capacitor, 30 Ω, open stub, ¼ λ at LO frequency.
C5—5- to 40-pF ceramic trimmer (15 pF nominal).
C6—100-pF silver mica.
C7—1000-pF feedthrough.

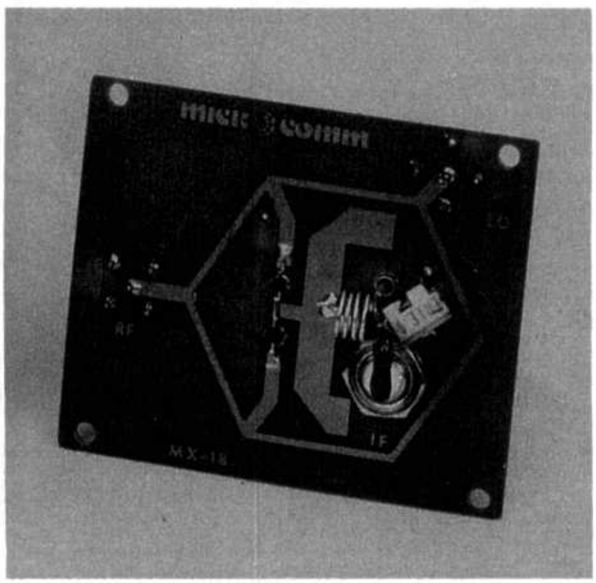
inputs in phase. Thus, both MMICs amplify the RF input signal, and an appreciable input-signal component exists at the outputs of the MMICs. To diminish the input-signal component present at the IF port, the IF impedance matching network (C3, C4, L1, C5) is employed as a low-pass filter.

Incidentally, in the intended application of this prototype mixer, the design IF is 137.5 MHz. The MMICs are designed for a nominal output impedance of 50 ohms each, thus their paralleled outputs represent roughly a 25-ohm source to the IF port. C3, C4, L1 and C5 were optimized to step this value back up to a 50-ohm match at the desired IF. Fig 6 shows the results of optimizing the IF match over the band of 100 to 175 MHz. The optimization was performed using SuperStar (S-parameter Two-port Analysis Routine), Randall Rhea's microwave circuit analysis package for the IBM® PC and compatible computers.[4]

Prototype Mixer Test Results

The prototype MMIC active balanced mixer was tested as a downconverter, under the conditions summarized in Table 2. The IF spectrum is shown in Fig 7, with vertical sensitivity of 10 dB per division, with 0 dBm at the top of the screen, and a horizontal sweep of dc to 2 GHz. Swept conversion gain is shown in Fig 8.

The prototype exhibits 18 dB of conversion gain at 1.7 GHz, with a 3-dB band-



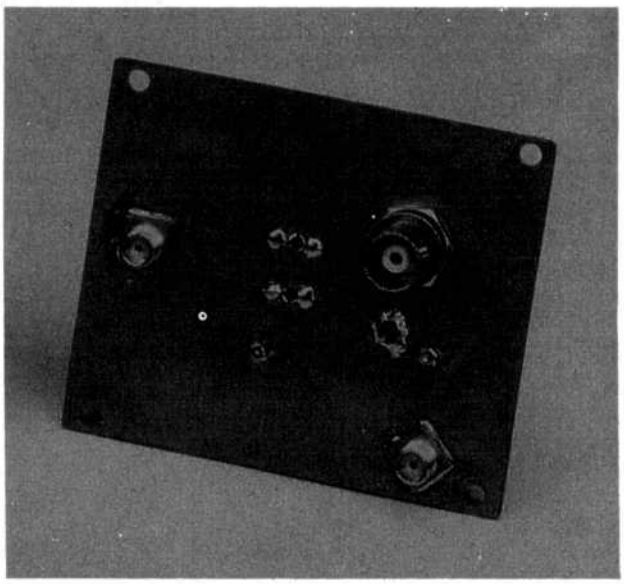


Fig 5—The prototype active balanced mixer is built on a substrate originally designed for use with a passive mixer. The MMICs are placed in the holes normally occupied by the hot-carrier diodes. A bias network has been added to the IF filter section.

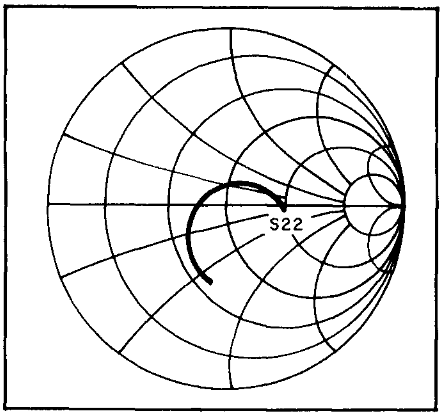


Fig 6—SuperStar plot of the mixer's IF port match, swept from 100 to 175 MHz.

Table 2
Prototype Active Balanced Mixer Test Conditions and Results

V_{CC} = +12 V; I_C = 30 mA

Port	*Frequency (MHz)*	*Amplitude (dBm)*	*Gain (dB)*
LO	1533	−15	N/A
RF	1691	−40	N/A
IF	138	−22	+18
	1533	−36	−21
	1691	−45	−5

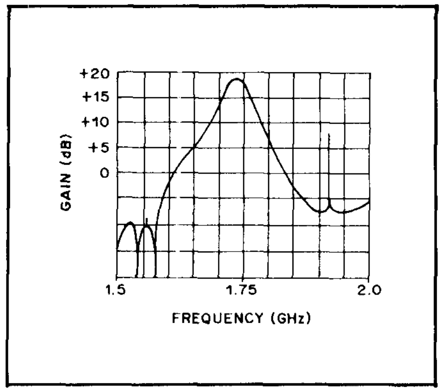


Fig 8—Swept conversion gain of the prototype MMIC active balanced mixer.

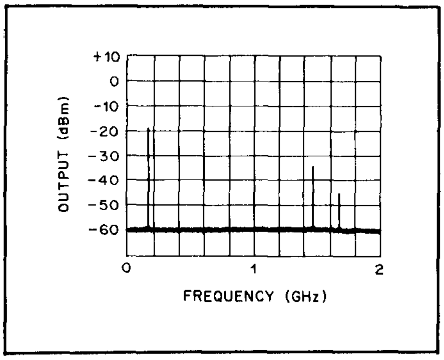


Fig 7—The output spectrum of a prototype active balanced mixer showing suppression of RF input-signal and LO components (see text).

width of more than 50 MHz, when driven with a 1.5 GHz, −15 dBm LO. LO components at the IF are suppressed by 21 dB, though the RF input-signal component at the output, as expected, is only slightly attenuated. A frequency selective IF amplifier stage following this mixer would significantly clean up the output spectrum.

Other Bands

The hexagonal rat-race configuration seen in the photographs has, over the fifteen years or so I've been building passive balanced mixers, become something of a signature. I like to think the hex shows there's still a bit of sorcery associated with microwave circuit design. I've used this mixer on all six ham bands between 900 MHz and 10.5 GHz, as well as for a number of commercial applications, including WEFAX, MDS, ITFS, TVRO, and various avionics services. The configuration has been widely published,[2,3,5,6] and even more widely imitated.[7] The time has come to share the secret of the hex design.

Think of the rat race coupler as being composed of six microstripline matching transformers, each a quarter wave long at the operating frequency. The trick is to define the operating frequency, as the coupler must pass both the RF input-signal and LO components. For optimum tradeoff between these two frequencies, design the arms to be a quarter wave at the *geometric mean* (square root of the product), rather than the *arithmetic mean* (half the sum) of the two frequencies of interest. Of course, the coupler has a finite bandwidth. For best results, these two frequencies should be within about ten percent of each other.

But how do you control the input-signal-to-LO separation? Simply by judiciously selecting your IF. Because of mixer bandwidth limitations, you would like to use the lowest possible IF. But image rejection demands the greatest possible separation of RF and LO components, hence, the highest possible IF. A paradox? Well, yes, but a good compromise seems to be to always convert down to about a tenth of the input frequency. (If you have to go further, use multiple conversion.) Fortunately, many of our "preferred" amateur conversion schemes are in the right ballpark: 1296 to 144 MHz; 2304 to 220 MHz; 3456 and 5760 to 432 MHz; 10,368 to 1296 MHz. And of course, 1691 (WEFAX) to 137.5 MHz.

As you might imagine, over the years I've taped up quite a few hex couplers for a number of different frequencies. For your convenience, I've included a few PC-board etching patterns in Fig 9. All should be etched on $\frac{1}{16}$-inch-thick, fiberglass-epoxy substrate, double-sided, 1-oz copper PC board and used for the frequencies indicated.

Summary

The prototype mixer met its original design objectives of conversion gain, low-noise performance, and operation at low LO injection levels. Reducing the quiescent current of the MMICs permits the efficient generation of sum and difference frequencies, which is the overall function of a mixer stage. The observed combination of low LO injection requirements, reasonable conversion gain, and noise figure established by the MMICs should significantly simplify RF-receiver design.

Notes

[1]R. Cooper, "Coleman Terminal Update," *Coop's Satellite Digest*, Oct. '79, p. T6.

[2]H. P. Shuch, "Rat-Race Balanced Mixer for 1296 MHz," *ham radio*, Jul 1977, p 33-39.

[3]H. P. Shuch, "Cost-Effective Modular Downconverter for S-band WEFAX Reception," *IEEE Transactions on Microwave Theory and Techniques*, Dec 1977, p 1127.

[4]SuperStar is available for $595 from Circuit Busters, Inc, 1750 Mountain Glen, Stone Mountain, GA 30087, tel 404-923-9999.

[5]H. P. Shuch, "Microstrip—Magical PC Technique Explained," *73 Magazine*, Oct 1978, pp 80-87.

[6]H. P. Shuch, "A High Performance Conversion Module for the 23-cm Band," *Radio Handbook* (Indianapolis: Howard W. Sams, 1975) 20th Edition, section 20-5.

[7]G. Roberts, "Fiddlers Corner Part II," *Journal of the Environmental Satellite Amateur Users' Group*, Vol 5, No. 1, Jan-Mar 1987, p 10.

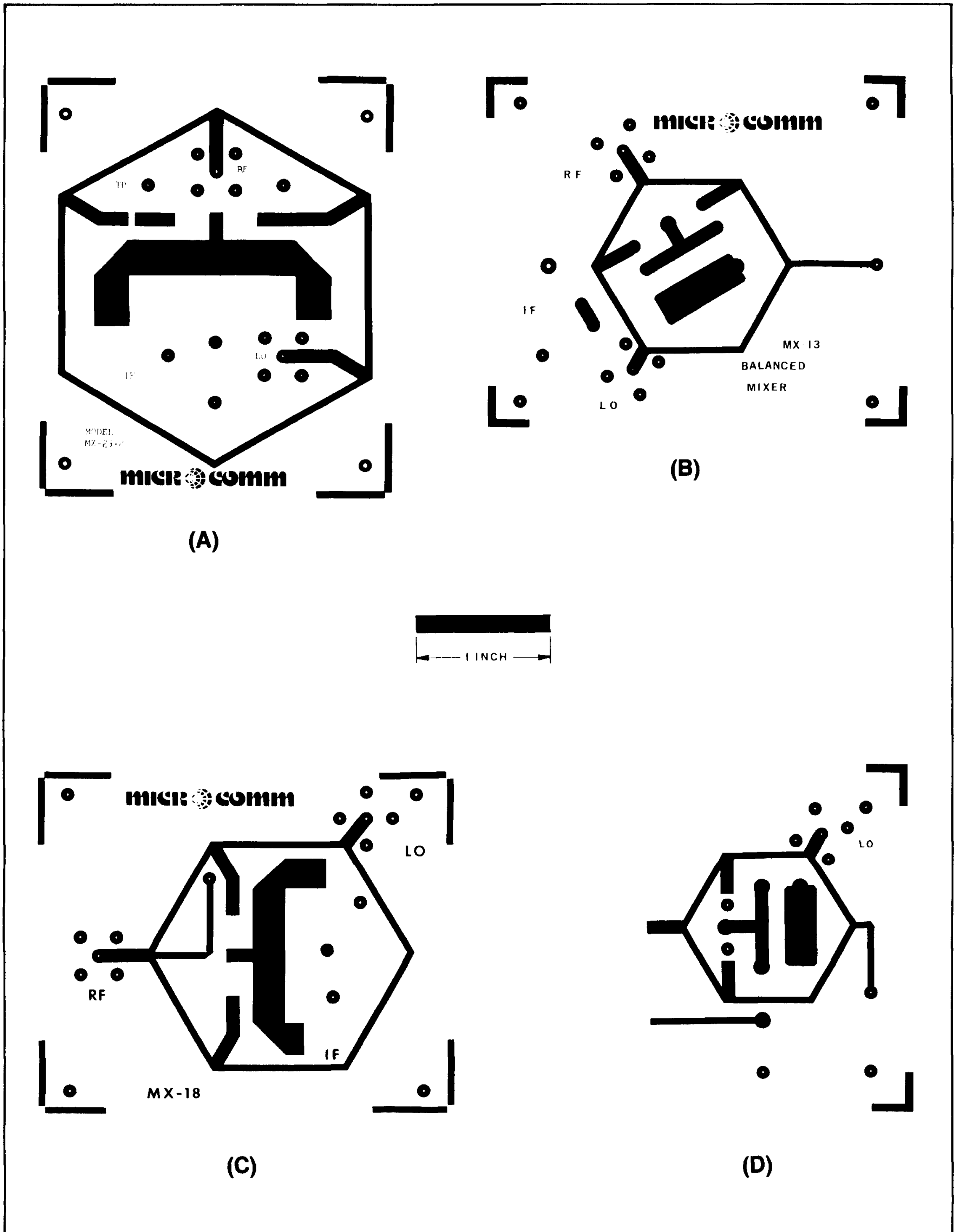


Fig 9—PC-board etching patterns for passive balanced mixers to be used on different frequencies: at A, 1296 MHz; B, 2304 MHz; C, 1691 MHz and D, 2.6 GHz.

The ACE Orbit: A New Communications Satellite Orbit

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A satellite in geostationary orbit provides communications services 24 hours a day whether its users need them or not. In the United States, satellite communications services are most in demand during the late morning and late afternoon. Communications during these peak hours could be provided by a satellite in a particularly advantageous non-geostationary orbit, avoiding the need for one of the coveted slots in the geostationary arc, at a cost per channel estimated to be 25% less than that for a satellite in Geostationary Earth Orbit (GEO).

The orbit making these advances possible is the *Apogee at Constant time-of-day Equatorial* or ACE orbit. Developed by Ford Aerospace Corporation, this innovation was studied under NASA-Lewis Research Center Contract NAS3-24891. Completed in May 1987, the study showed that the ACE orbit possesses important advantages over the Molniya orbit, which is the principal non-geostationary orbit used for telecommunications today.

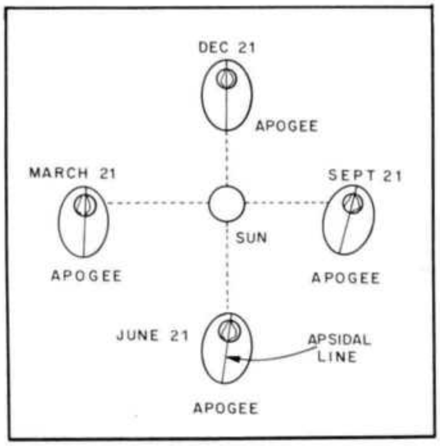


Fig 1—Since its orbit orientation moves with respect to the Earth-Sun line, a Molniya satellite does not cross apogee at the same time of day throughout the year.

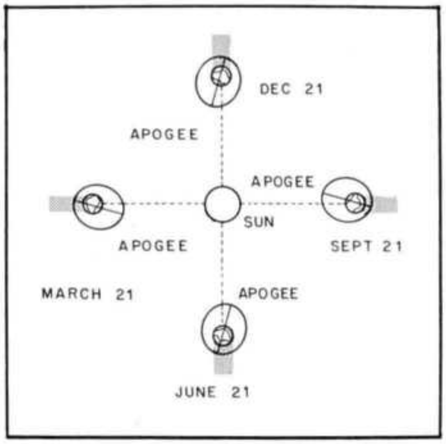


Fig 2—ACE orbit orientation remains fixed relative to the Earth-Sun line, so the apogee is overhead at the same time of day all year long.

The Molniya Orbit

Virtually all non-geostationary communications satellites are operated by the Soviet Union in Molniya orbits. Typical Molniya orbits are highly elliptical, as shown in Fig 1. Satellites in such orbits loiter near apogee, the highest point in the orbit, where they are useful for telecommunications. They pass quickly through the lowest point in the orbit, the perigee, where they are too low and moving too rapidly to be of use.

The Soviets pioneered the use of the Molniya orbit in 1965, and operate at least a dozen Molniya satellites at any one time. Over 80 have been launched during the past 20 years. However, this type of orbit has not caught on in the commercial world, doubtless because at least four Molniya satellites are needed to provide year-round coverage at peak hours of the business day.

The reason for this multi-satellite requirement is displayed in Fig 1. A Molniya satellite providing coverage at noon in December could provide communications service only during the night in June. Many satellites, with apogees located all around the earth, are needed. Each will provide daytime service in turn as the year progresses.

The ACE Orbit

A single ACE orbit satellite can do the job of several Molniya satellites in providing constant time-of-day coverage throughout the year. Fig 2 shows how the orbit of the ACE satellite reorients itself to maintain its apogee in the same position with respect to the sun. Thus, the useful apogee region remains above a specific time zone throughout the year.

What causes the ACE orbit's apogee to follow the sun? This rotation, known as *apsidal rotation*, is due to the non-uniform mass distribution of the earth. The earth's equatorial radius is actually 21 km greater than its polar radius. Therefore, the tropical region of the world contains disproportionately greater mass. This extra matter exerts a gravitational force upon an orbiting satellite, altering the orientation of its orbit in space. If the plane of the orbit lies in the plane of the earth's equator, the orbit's elliptical shape will rotate within the equatorial plane. The lower the orbit, the more rapidly the apsidal line—the line connecting orbit perigee and apogee—rotates.

By constraining the radii of the orbit's perigee and apogee, the apsidal rotation rate can be set to 360 degrees per year, thus making orbit apogee follow the sun. The apsidal rotation rate is then said to be *sun-synchronous*.

A second condition must be satisfied if the satellite is to be of commercial use: Its period of revolution must be a simple fraction of a day. This ensures that the satellite will reach apogee at the same time of day every day. Orbital period is set by constraining the arithmetic mean of the radii of the perigee and apogee.

The ACE orbit, which satisfies both constraints, has a period of one-fifth of a day or 4.8 hours, a perigee radius of 7410 km and an apogee radius of 21,480 km. Perigee altitude is 1030 km and apogee altitude is 15,100 km. For comparison, a geostationary orbit is circular with a radius of 42,160 km and an altitude of 35,790 km. This sets its period to one day.

Figs 3 and 4 show how ACE orbit satel-

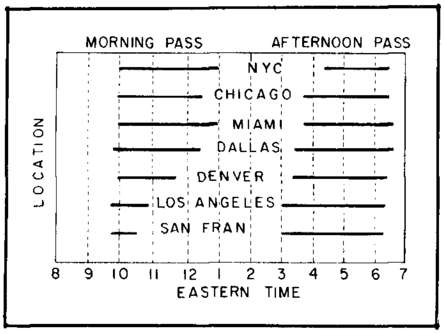


Fig 3—Coverage of major US cities that can be provided by a single ACE orbit satellite.

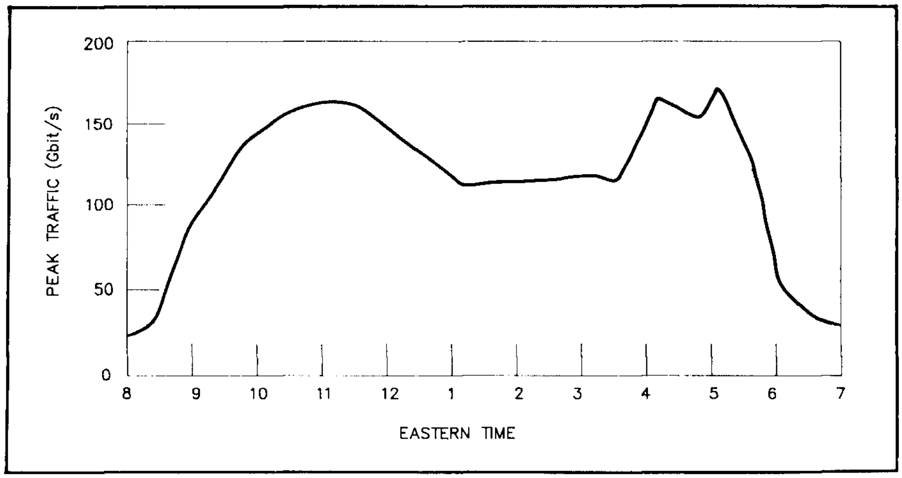


Fig 4—Satellite addressable traffic displays morning and afternoon peaks.

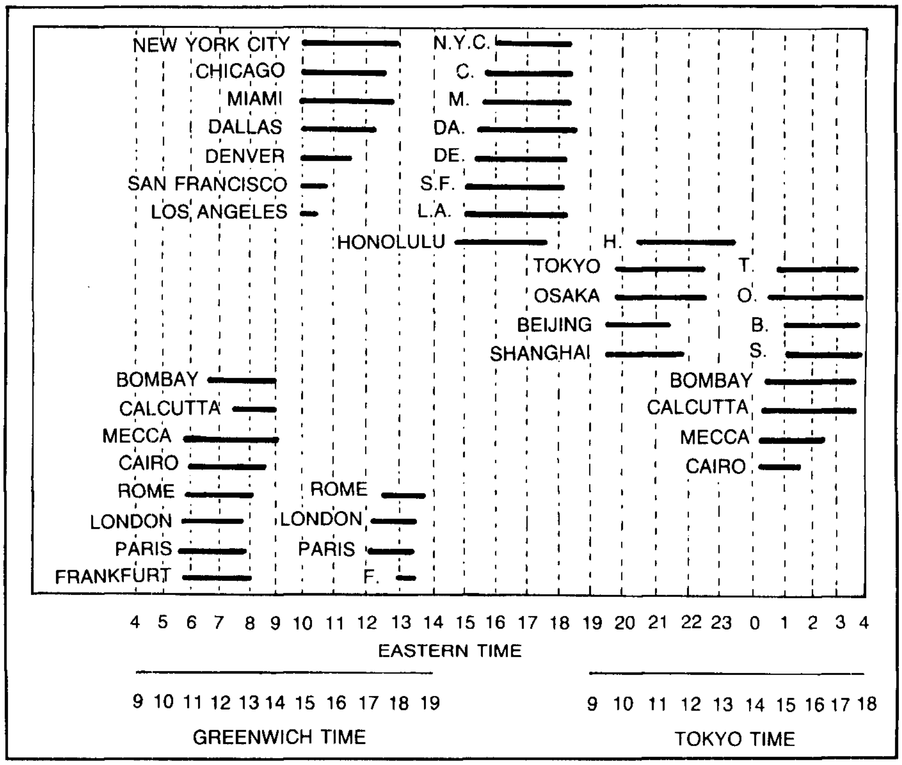


Fig 5—A single ACE orbit satellite provides worldwide coverage. Coverage times for Japan are almost identical to those of the US East Coast.

lite coverage can address peak loads in the US domestic satellite communications traffic. East Coast and Midwest coverages were optimized by placing one of the satellite's apogee-crossings at 48 degrees W and setting the time of the crossing to 11:50 AM EST. Next apogee occurs 4.8 hours later at 120 degrees W, so both US traffic peaks are serviced.

Advantages of the New Orbit

A host of advantages favor the ACE orbit compared with the geostationary orbit. These include improvements in communications link budget, launch vehicle payload mass and worldwide communications capability from a single satellite.

Signal free-space losses and propagation delays are both considerably smaller for an ACE orbit satellite than for a geostationary satellite. This is due to the lower altitude of the ACE orbit, which results in a reduced slant range between a ground terminal and a satellite in the orbit. Free-space loss is approximately 7 dB less for an ACE orbit satellite than for one in GEO. This factor increases signal strength for the same antenna/transponder combination by a factor of five, an impressive link budget improvement that could be used to dramatically reduce ground terminal antenna size. Typical two-way propagation delay between a geostationary satellite and a US ground terminal is 0.25 second, but for an ACE satellite the two-way delay is a mere 0.12 second.

Launch vehicles operating out of Cape Canaveral can inject at least 40% greater payload mass into the ACE orbit than into GEO. The use of the Kourou, French Guiana launch base would enable a given vehicle to put over 80% greater mass into the ACE orbit. This would make it possible to place large, relatively complex payloads aboard spacecraft so that the size and cost of ground terminals can be reduced.

Based on a life-cycle cost comparison of an ACE orbit satellite and a GEO satellite, the NASA study estimated that per-channel costs for an ACE orbit satellite would be about 25% lower than for a geostationary satellite. Of course, the ACE orbit satellite is available only during the 5- to 6-hour peak traffic time of day for US communications service. This limitation in availability makes the ACE orbit unsuitable for providing 24-hour services such as broadcast TV. However, availability coincides with peak telecommunications traffic, as shown by comparing Figs 3 and 4, and thus has the potential to satisfy many user needs.

Single-satellite worldwide communications is also a possibility for the ACE orbit. The ACE satellite crosses apogee five times a day, and the five daily apogees occur at longitudes spaced 72 degrees apart. The US can be viewed from two of the daily apogees. The other three will be in view of other regions of the world including Japan and Europe.

Fig 5 displays the worldwide coverage times for the ACE satellite whose domestic US coverage periods are dis-

Continued on page 14.

Correspondence

Tropo Backscatter

Because of the high gain/narrow beamwidth antennas used on the microwave bands, it's almost impossible for stations outside of the direction in which the antenna is pointing to participate in roundtable QSOs. During a QSO in April 1980, B. J. Klausen (OZ8WK), Morgan Larsson (SM6ESG) and I (SM6HYG) found a way to communicate between the west coast of Sweden and the eastern coast of Denmark on the 23- through 3-cm bands.

As you can see from the map in Fig 1, the path between my station and OZ8WK's is about 150 km, mainly over water, with no high mountains in between to interfere with our signals. Despite the good path, all attempts to QSO on 13 cm were unsuccessful, even when signals on the 70- and 23-cm bands were RS 59 at both ends.

During one of the QSO attempts, SM6ESG was able to hear my signals on 13 cm at S 5 to 6, when he was beaming toward OZ8WK. In fact, no signals would cross the direct path between me and SM6ESG; we could only hear each other when we both aimed our antennas at OZ8WK. What was causing this reflection? Why didn't OZ8WK hear me at all? OZ8WK was hearing SM6ESG with good signal strength, so there appeared to be some sort of a wall between me and OZ8WK.

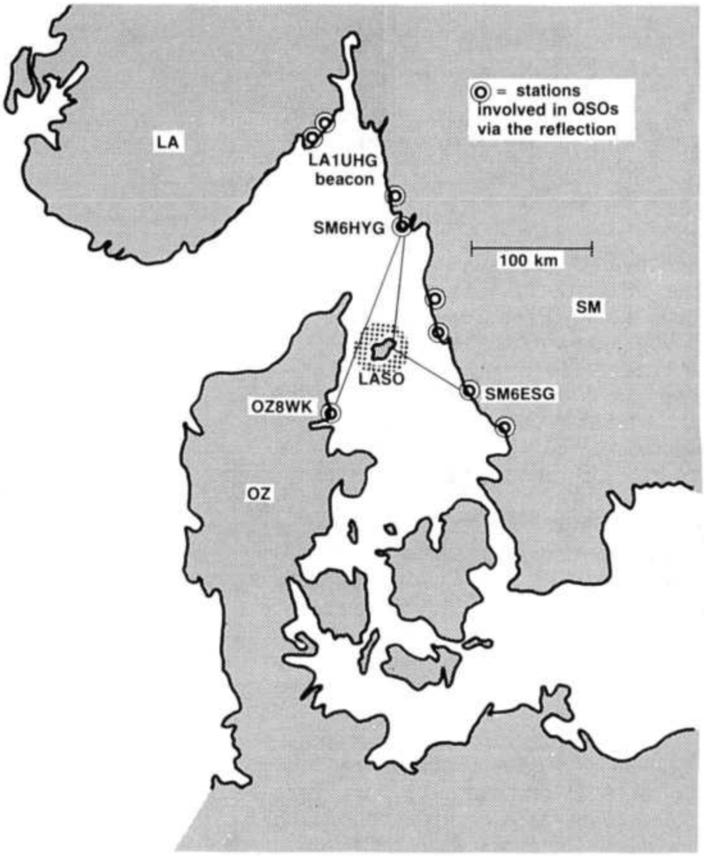


Fig 1—Station locations and signal paths involved in the 23- through 3-cm-band QSOs.

A closer look at a map covering the sea between Sweden and Denmark showed the small island of Laso with its shallow sand beaches. For several hundred meters around Laso, the surrounding water is only a few meters deep. On a clear, calm spring day when the sun heats up that water, a bubble of hot, humid air rises above the island. Because of the rapid change in the refraction index, there is no way for the microwave signals to penetrate the wall. Instead, the signal is scattered in different directions, making QSOs possible with the beam headings shown in Fig 1. Because of the scattering effect, the signals get distorted, sounding like modulated raw ac, and there is a phase shift as the beam heading is altered. If one operator changes the direction of his antenna, the other station has to change his antenna direction, too—probably to maintain the proper angle for signal reflection. The total angle that can be used on either side of the optimal point is much smaller at my location than at SM6ESG's because of the different distances between the stations and the point of reflection.

Since the first QSO, several hundred QSOs involving many stations have taken place on all frequencies from 23 to 3 cm. Even the LA1UHG beacon on 10.368 GHz has been heard this way. What happened to the "impossible" 13-cm QSO between me and OZ8WK? Well, we just had to wait for a day with equal temperature along the whole path, and the QSO was made with ease. Probably there are many locations in the world where this kind of tropo backscatter propagation is possible. Why don't you try it the next time a direct-line QSO doesn't work?—*Carl Gustaf Blom, SM6HYG, Kronbengsg 39, S-45300, Lysekil, Sweden*

Feedback

Dennis L. Haarsager, N7DH, reports an error in his January 1989 *QEX* article, "Path Selection—Part 2." In Eq 17, p 10, the variable labled D_m should be D_a.

Also, the latitude given for Kamiak Butte in the first paragraph on p 10 under Examples is incorrect. It should be 46°, not 47°.

Bits

Gassol Soldering Tool

Samper Co, of Jersey City, New Jersey, has introduced the Gassol butane-operated soldering tool. One butane filling operates the Gassol unit for 60 minutes. Easy refilling, temperature adjustment and tip replacement are features of the unit. Soldering tips from 1 to 4.8 mm, as well as a burner tip, are available. Soldering-tip temperature is 1300°C. For more information, contact Samper Co, 142 Newark Ave, Jersey City, NJ 07302, tel 201-333-1598.

>50
Focus on technology above 50 MHz

By Bill Olson, W3HQT
Box 2310, RR 1
Troy, ME 04987

Reflector Antennas: Dish Construction and Surfacing

In the last two columns, I discussed reflector antennas in general, and parabolic-dish-feed antennas. This month, I'll talk briefly about the reflector surface itself and some of the mechanical considerations associated with putting up a dish. This is not a how-to-build-a-dish article. You are urged to consult the literature for help in home-brewing a dish.[1,2,3,4] There are so many small- to medium-sized dishes around these days on the surplus and junk scene that it just doesn't make much sense to home-brew anything smaller than 10 or 12 feet in diameter. To put together a bigger dish—say, for EME on 432 MHz—home-brewing could be the most cost-effective route, because, although there are 20- and 30-footers out there on the scrap market, transporting them is no easy feat!

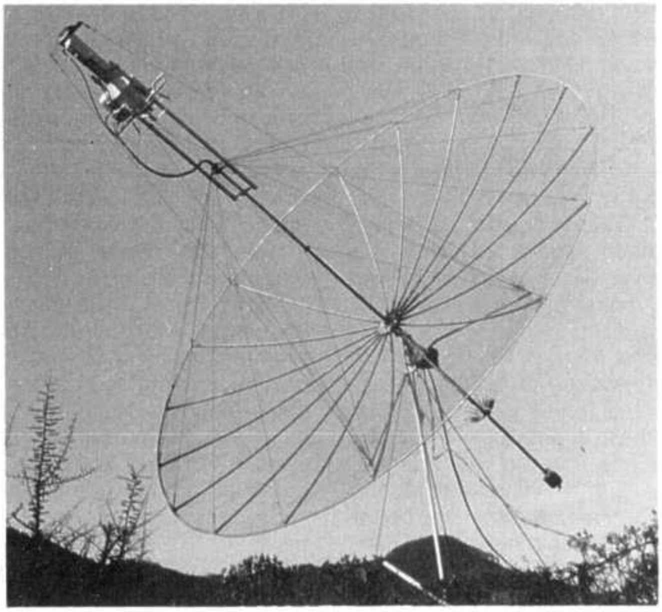


Fig 1—A stressed parabolic dish. A network of nonconductive cables attached around the perimeter of the dish and to a mast running through the focus of the dish hold the reflector shape. This 20-foot dish belongs to F2TU, who uses the antenna for EME work on 432 and 1296 MHz.

Reflector Types

Parabolic reflectors come in several styles. The smaller ones are almost all rigid dishes of some type, and have either a solid reflecting surface or a mesh surface. Another variation on the theme is the reflector often used for UHF TV antennas where parallel, horizontal aluminum rods are bent into a parabolic shape. Solid dishes can be all metal (usually aluminum), or metallized fiberglass. Mesh dishes can be perforated or expanded aluminum sheet, or wire mesh. Many home-brew dishes use chicken wire or hardware cloth as the reflecting surface.

Big dishes (over 10 feet in diameter) are usually covered with some sort of mesh to reduce wind loading. These babies can also be rigid parabolas, stressed dishes (where the outer edges of the dish are pulled into the proper position by nonconductive lines attached to the feed support—sort of like an upside down umbrella—see Fig 1), or combinations of the two. Rigid dishes usually have trusses to hold the shape of the reflector, and are stronger—but they weigh a *lot* more. (See Fig 2.)

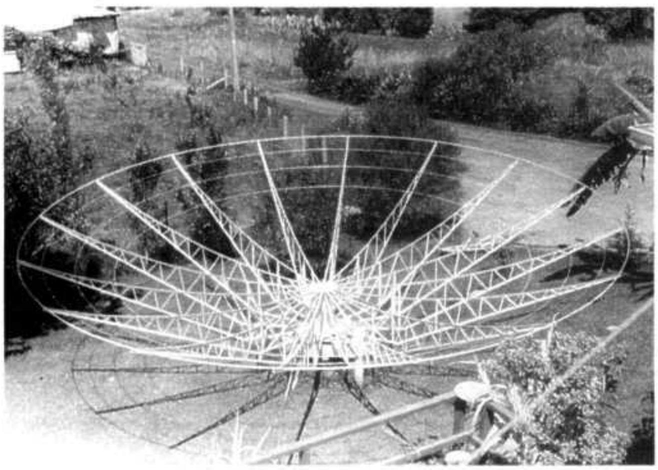


Fig 2—A rigid-truss parabola. Dishes constructed in this fashion are far heavier than stressed dishes, but trussed reflectors can be made very large because of the inherent durability of their construction. This 23-foot monster dish belongs to ZL1BJQ.

What's It Good For?

Because I've decided that very few of you will try to build a thirty-footer from scratch from a *QEX* article, I will concentrate here on using an existing reflector on the ham bands, or modifying an existing dish toward the same end. Basically we need to know three pieces of information before we start: (1) diameter—this allows us to calculate gain; (2) focal-length-to-diameter ratio (f/D), so we can design the feed antenna; (3) surface accuracy and mesh size, so we can find the upper-frequency limit of the reflector.

The first two numbers can be obtained with a 2 × 4 and a tape measure. The

[1]Notes appear on page 12.

third is a little more tricky. If you know what frequency the dish was originally used at, you can be confident that it is usable *below*, and probably somewhat above, this frequency. The problem is that, as frequency is increased, the surface must be closer to a perfect parabola for us to realize the optimum gain from a reflector. At the same time, the mesh size must be small enough that most of the signal gets reflected in the desired direction, and doesn't shoot through the back of the dish.

Gain Deterioration from Surface Inaccuracies

Accuracy of a dish surface affects the upper-frequency limit at which the dish can be used. (To turn this around, knowing the required surface accuracy at a given frequency will tell us how sloppy we can be in constructing a parabolic reflector!)

Irregularities come in two forms. The first has to do with how much the reflector varies *overall* from a true paraboloid; the second has to do with individual areas of deviation, and how big they are relative to a wavelength. Without getting too deep into this, remember that it is better to have small areas that are way off than to have the whole dish be moderately off. To put it another way, short-range irregularities such as small dents, bolt heads, holes, and so on, can usually be ignored, but long-range irregularities (such as the dish not being a true paraboloid) can seriously hamper antenna performance. Usually, we would like to keep the long-range accuracy better than $\frac{1}{20}\lambda$ to keep the gain degradation under 1 dB. This is 1½ inches at 432 MHz. Of course, small irregularities can be much worse (even up to 4 or 5 inches at 432 MHz), as long as they are not too big.

Gain Deterioration as a Function of Mesh Size

If the wire-to-wire spacing of a mesh-covered dish is too large with respect to the wavelength, some amount of signal will pass through the reflector, resulting in decreased gain and increased noise pickup (reduced front-to-back ratio). The amount of performance degradation depends on a number of factors, including polarization, mesh-wire size, and wire spacing.

For wire meshes such as chicken wire, where the spacing is much greater than the wire diameter, a mesh size of less than 1/10 λ will result in less than 1 dB of gain reduction. This makes 1-inch chicken wire okay at 1296 MHz, but a little too big at 2304 MHz, where 1-inch mesh would cause loss of around 3 dB. Of course, if you already have the dish, even with the 3-dB loss, you might have a heck of an antenna—and you could cover the center portion (where most of the gain comes from) with a smaller mesh, if necessary. Al Ward, WB5LUA, has made numerous EME contacts on 2304 MHz with a 20-footer covered with 1-inch chicken wire, for example.

Mechanical Considerations

A few last-minute notes here: Remember, the main disadvantage of a dish antenna, at least as far as I see it, is very high wind-load-to-gain ratio. A 100 mi/h wind has an impact pressure of *40 pounds per square foot* of antenna area. An eight-foot dish has a worst-case wind area of 50 square feet. Anybody want to guess what a *ton* of horizontal pressure will do to most masts? Keep this in mind when putting up a dish. Make sure to feather it into the wind when it's blowing, or point it up in the air—bird-bath style—if that's possible.

Mesh dishes have lesser wind-load problems than their solid-surface brethren, but a little freezing rain can make a solid surface out of mesh. In any case, mount a dish with the thought in mind that the mounting hardware and support will have to put up with a lot of pressure in bad weather.

Conclusions

There are a lot of dishes available out there. One ham put a want ad in the local paper—he was looking for just a TVRO dish, no electronics—he had three or four *the first day*. This kind of thing happens for all kinds of reasons: People move and don't want to move the dish . . . new owner thinks it's an eyesore . . . smaller dishes are available at flea markets and swap meets, and so on. UHF TV dishes used to be the rage on 1296—just cover them with chicken wire. If you can keep one up, it makes a decent antenna. Have fun!

New Products for the >50 Audience

Avantek has released a series of silicon MMICs that use isolated collectors. They call their manufacturing method the Isosat™ process.[5] This process has allowed Avantek to optimize device feedback for flat gain and low noise. The new device is designated the INA 02170, and, at this point, only comes in the 70-mil hermetic (read: expensive) package, but will be available soon in the familiar plastic MMIC package. The device is unconditionally stable, and performance is as follows:

Frequency (MHz)	*Gain (dB)*	*Noise Figure (dB)*
432	32.5	1.75
902	32	2.0
1296	27	2.3
2304	16	3.75

For more information, contact your local Avantek sales office.

Another new product of note is the Mitsubishi M67715. This is a hybrid linear-power-amplifier module designed for about 10 mW drive and 3 to 4 W output at 1296 MHz. Saturated output is about 5 W. This module replaces the NEC MC5874, and is used as an output stage in 1290-MHz hand-held rigs, and as a driver in multimode rigs in the 10-W-output class. Mitsubishi is expected to market this product on a small-quantity basis in the near future.

Notes

[1]P. Laakmann, "A Large Homebrew Parabolic Reflector," *ham radio*, Aug 1970, p 8.

[2]R. T. Knadle, Jr, "A Twelve-Foot Stressed Parabolic Dish," *QST*, Aug 1972, p 16. Also see G. L. Hall, ed, "A 12-Foot Stressed Parabolic Dish," *The ARRL Antenna Book*, 15th edition (Newington: ARRL, 1988), pp 19-16 to 19-22.

[3]T. R. Naughton, "Parabolic Reflector Antennas," *ham radio*, May 1974, p 12.

[4]A. Katz, "Simple Parabolic Antenna Design," *CQ*, Aug 1966, p 10.

[5]C. C. Leung, T. C. Lo, M. Dutta, I. Kipnis, J. Kukielka and C. P. Snapp, "Bipolar Process Produces Si MMIC Building Blocks," *Microwaves and RF*, Vol 27, No. 5, May 1988, p 231.

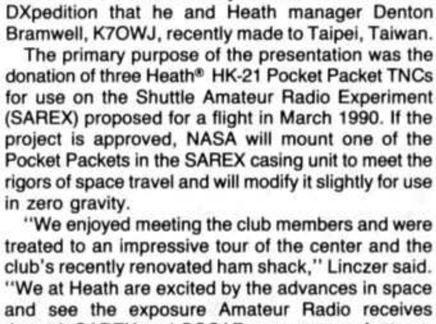
Bits

Heath's HK-21 Pocket Packet TNC Donated for Use In Space Shuttle

Wayne Wilson, WB8TSO, product line manager for Heath's Amateur Radio products, and Ron Linczer, manager of marketing communications, attended the November 17, 1988 meeting of the Johnson Space Center Amateur Radio Club. At the meeting, Wilson discussed the innovative products Heath has introduced over the last year and described the DXpedition that he and Heath manager Denton Bramwell, K7OWJ, recently made to Taipei, Taiwan.

The primary purpose of the presentation was the donation of three Heath® HK-21 Pocket Packet TNCs for use on the Shuttle Amateur Radio Experiment (SAREX) proposed for a flight in March 1990. If the project is approved, NASA will mount one of the Pocket Packets in the SAREX casing unit to meet the rigors of space travel and will modify it slightly for use in zero gravity.

"We enjoyed meeting the club members and were treated to an impressive tour of the center and the club's recently renovated ham shack," Linczer said. "We at Heath are excited by the advances in space and see the exposure Amateur Radio receives through SAREX and OSCAR as a means of attracting new, young amateurs." *—Paul K. Pagel, N1FB*



Wayne Wilson, WB8TSO, of the Heath Company (third from the left) presents Gil Carman, WA5NOM, the Johnson Space Center Amateur Radio Club President, with a Heath HK-21 Pocket Packet TNC. Club members Gerry Creager, N5JXS (second from the left), and Lou Mc Fadin, W5DID (right), look on.

VHF+ Technology

By Geoff Krauss, WA2GFP
16 Riviera Drive
Latham, NY 12110

How One VHF+er Found a New Use for Winter Evenings *or* Is It Too Early to Begin Spring Cleaning?

I've been doing quite a bit of shack cleaning over the last several weeks. With all the building and experimenting I do, there is usually little time left to put everything away in its proper space (if you're anything like me, you have much more gear than space, anyway!). Since I was first licensed back in '57, and began VHF+ building almost at once, I have the best of over 30 years of equipment taking up most of my attic, two-car garage, enclosed back porch, spare bedroom, and so on.

What I had even more of, though—we'll get to why it's *had*, instead of *have*, in a minute—was a full 30+ years of paper: books, magazines, articles, notes, conference handouts, and so on. All told, it came to eight file cabinets of sorted material, plus a dozen bookshelves and piles of unsorted data all over the shack floor. For years, my wife had asked me to reduce the volume of this collection, but I just couldn't bear disposing of such things as my fantastic collection of special purpose-receiving-circuit papers. Alas! I now finally realize that I am never going to design and build my VHF version of the 75A-4: a six-band (50-144-220-432-902-1296-MHz), single-band-switch receiver project I started 25 years ago, and for which I've saved data and parts ever since. I had a few other projects of that ilk: vaguely defined pieces of equipment that I had once greatly desired, and for each of which I had collected *some* parts (often basing the whole project on a newly available "wonder" part), and started at least one information file, complete with a copy of everything I could get my hands on that related, even vaguely, to that particular project.

I don't know what actually started me on this clean-up campaign; perhaps it was the time I tried to ease my way around a 3-foot-high pile of GaAsFET data sheets and bumped into my old APX-6 WBFM transceiver, which fell on my foot, hurting it a *lot*. Anyway, after many weeks of emptying out drawers and shelves, I have come to several important conclusions: My trashman hates to lift trash bags that contain 50 to 60 pounds of old junk—that possibly has no earthly use—each; a local Boy Scout, who gratefully carts off huge mounds of recyclable paper from my house each week as part (perhaps even all) of the neighborhood scrap-paper drive that serves as his project for the Eagle Award, has started to ask questions about the funny drawings all over that paper, and whether it relates to the funny antennas on my roof and car; and a few local hams, having shown some interest in VHF+, have been the recipients of mystery boxes—filled with some less-than-state-of-the-art gear, related papers and somewhat out-of-date books—left on their doorsteps.

Will the outcome of this cleanup be more space for my family, more order and safety in my shack, more active VHF+ers among the local amateur population, and perhaps even a new ham or two? I don't know yet, but it's possible. Might *you* be considering undertaking a similar cleanup this spring?

Mystery of the Missing Cavities

The 33-cm (902-MHz) band should be the next in my consideration of what is state-of-the-art for the VHF+er, but, as I wrote in a previous column, Bill Olson, W3HQT, covered that band in >50 ("33-cm Band Survey," *QEX*, Feb 1988, pp 12-13). One 33 cm topic might possible stand treatment here, however. Rumors keep surfacing about a problem concerning 800-MHz power amplifiers (each of which apparently contains an Eimac tube/cavity capable of several hundred watts output) that are being decommissioned by large companies (Motorola Communications is the name most frequently mentioned). For a while, the units were supposedly being sold as scrap for something like $50, their buyers making them available at various flea markets (I'm told that a number of these units were available at the Dayton HamVention®). For some reason, however (often reported as the cavity source[s] getting really upset at the news that scrap buyers were selling the scrapped cavities for *six to ten times* the scrap price), the source(s) are now supposedly *destroying* the amplifiers as they are decommissioned.

Anyone considering doing serious work at 903 MHz knows the importance of the availability of such amplifiers to the growth of amateur activity on the 33-cm band. Perhaps a special arrangement could be made (say, a charitable donation of cavities to a ham organization that could place the cavities in the shacks of radio operators *who are ready to use them* [such eligibility to be based, perhaps, on local verification that each cavity candidate already has a low-power 33-cm station in place]). Accordingly, I'd like to receive *factual* information on this cavity situation, as well as anything any reader might know about who to contact at the potential source(s) of these cavity/amplifier units. Let *me* know if *you* know!

1988 Conference Proceedings

Proceedings of the 22nd Central States VHF Society Conference (1988) and the 1988 Microwave Update (run by Don Hilliard, WØPW, at the end of each summer) are now available from ARRL HQ for $12 each. These volumes contain much good information, and the form and clarity of the text is excellent (not like some of the material that VHF+ers of longer experience may remember from certain conferences many years ago); even the pictures are clear and usable, with each circuit element recognizable. I can find only one shortcoming: The scale of some of the PC-board artwork is not called out, leaving the question of whether or not such drawings are rendered at 1:1.[1] So, before you cut and etch expensive PC board in response to a given article, contact the article author for possible corrections and updates.

If you've been thinking about generating VHF+ signals by using a surplus microwave "brick" oscillator (which seem to be readily available for between $10 and $35), for instance, *Microwave Update '88* contains a presentation by Charles Osborne, WD4MBK, called "Surplus Microwave Local Oscillators: Evaluating and Modifying Them." In my opinion, this article alone is worth the cost of the book. So, too, is "Simple Low Noise Microwave Preamplifiers" by Al Ward, WB5LUA. This article describes, with easily reproducible artwork, a series of one- and two-stage LNAs for 2304, 3456, and 5760 MHz, and 10.368 GHz, none of which require tuning adjustments. Al Ward also

[1]Both publications carry disclaimers stating that the papers they contain are unedited and are solely the responsibility of the authors.—*Ed.*

presented these LNAs at the 1988 Middle Atlantic (Packrats) VHF Conference, where I had the opportunity to acquire a couple of boards for each of the two-stage units. (Now, all I need to find is a source of the Avantek GaAsFETs [ATF10135 below 10 GHz, and ATF13135 above] so I can try the LNAs myself! I don't know of any readily accessible source of these GaAsFETs for small-quantity purchasers; I'd welcome such information, and will pass it along to VHF+ Technology readers as I receive it.)

In presenting the LNAs, Al mentioned that the monolithic amplifiers now available from Mini-Circuits (PO Box 350166, Brooklyn, NY 11235-0002) have part numbers similar to those of Avantek parts because Avantek makes Mini-Circuits' MMICs! (It's always nice to have a second source, especially if you're an amateur experimenter, even though most distributors have a fairly high minimum-order price.) It's interesting to note that these monolithic amps are apparently available only from US sources (Avantek is the only US MMIC manufacturer I know of); conversely, there are very few US makers of some other high-tech semiconductor devices, such as affordable GaAsFETs. Interestingly, Avantek is one of the few US GaAsFET manufacturers! (How many of us already knew *that*?)

Speaking of GaAsFETs and LNAs, it has been a number of years since I've carried out one of my LNA surveys, in which I build a large set of amplifiers, with different devices, for each of our VHF+ bands, measure the performance of many commonly-available devices, and present the information to my readers. Because my employer does not make these devices (except for some HEMTs for in-house use), I feel that my providing an impartial state-of-the-art survey every few years can be of great help to all. One of the most important facets of such a survey now is to evaluate some of the more recent innovations in LNA-input-circuit design. One such innovation is the use of a cavity in the LNA input circuit. Used in this way, a cavity can provide the impedance match necessary for the lowest NF *and* narrow band-pass filtering to reject unwanted signals adjacent to the desired frequency. I have seen some of these units at VHF+ conferences in the last couple of years, but I've yet to see an article or a set of results on this technique. If *you* have done work in this area, I'd like to make your information available to VHF+ readers; I'd like to avoid reinventing the wheel or taking credit for someone else's work. So, if you've developed a good cavity-input LNA, write an article for *QST* or *QEX*, or, if you'd rather not be that formal, send the information to this column.

The ACE Orbit:
Continued from page 9.

played in Fig 3. There are extensive periods of simultaneous coverage for cities in East Asia, the Mideast and Europe, and one hour of transatlantic coverage. Coverage always occurs during the day because orbit apogee is maintained almost directly between the earth and sun, as Fig 2 indicates. Japanese coverage times are particularly attractive; they are almost exactly the same as US East Coast coverage periods. Thus, a single satellite can address communications markets all over the world.

Technical Challenges

It might seem that the ACE satellite would pass directly between a US ground terminal and a geostationary satellite due to the fact that the ACE orbit lies in the earth's equatorial plane. On the contrary, this problem does not exist for any country well away from the equator. Fig 6 shows that when the two orbits are viewed from a point in Miami, Florida, they are separated by over five degrees of angle, more than twice the minimum separation permitted between GEO communications satellites. Naturally, care in the design and operation of an ACE satellite would be necessary to prevent its antenna beams or side-lobes from causing interference in the equatorial regions.

There is one substantial disadvantage to the ACE satellite: A ground terminal must be equipped with an antenna capable of tracking the satellite as it moves eastward across the sky. However, the tracking pattern would be the same every day: a relatively simple motion at approximately one degree per minute across the southern sky for a US ground terminal. The potential reduction in ground terminal antenna size made possible by the improved link budget of the ACE orbit satellite could well compensate for the increased costs incurred by the need for tracking. Many existing satellite antennas are capable of slewing from one geostationary satellite to another at rates of one degree per minute or better and might well prove easy to adapt for use in conjunction with an ACE satellite.

A second disadvantage is the high radiation environment in which the ACE satellite operates, since its orbital path carries it through the Van Allen radiation belt's equatorial region. Thus, it is exposed to higher doses of charged particles than geostationary satellites, which would affect the solar arrays and electronics. For a satellite shielded by 2.5 mm of aluminum, the total radiation dose in the ACE orbit is more than three times greater than in GEO and nearly five times greater than the dose received in a Molniya orbit.

Solutions to the radiation problem include thicker shielding or the use of radiation-resistant hardware pieces originally developed for military programs. The components of an ACE orbit satellite shielded by 4.5 mm of aluminum would receive the same radiation dose as those of a geostationary satellite with shields only 2.5 mm thick. Therefore, the expected shielding mass increase would be well below the increase in total satellite mass afforded by the use of the ACE orbit. Gallium arsenide (GaAs) or indium phosphate (InP) solar arrays currently under development would have higher sunlight/electricity conversion efficiencies than the less radiation-resistant silicon arrays.

The Promise of the ACE Orbit

The study of non-geostationary commercial communications satellites carried out for NASA concluded that the ACE orbit has considerable potential for new telecommunications business. Low user costs, the absence of a need for a slot in the geostationary arc, and worldwide service capability for a single satellite—all are new opportunities afforded by this Ford Aerospace innovation. The issue now is one of matching the availability of the ACE orbit satellite with a communications service or user need that can take advantage of its economic benefits.

About the authors

Andrew E. Turner is a senior research and development engineer, and Kent M. Price is a principal engineer in the space systems division at Ford Aerospace Corp in Palo Alto, California.

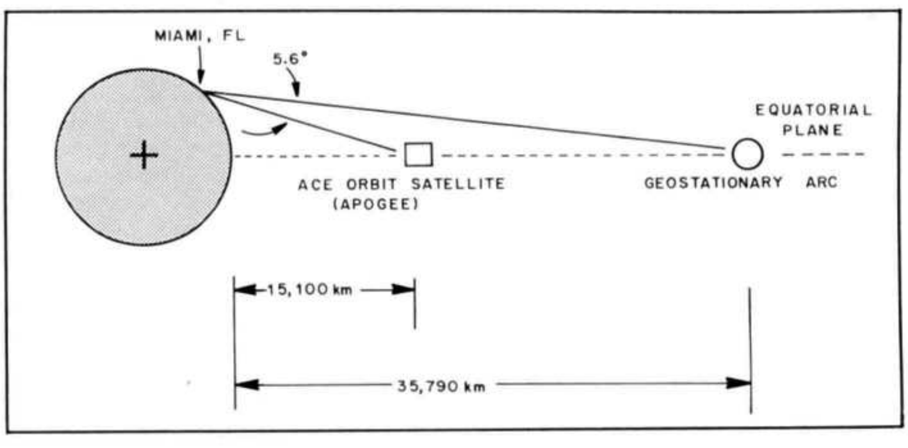


Fig 6—An ACE orbit satellite never comes within five degrees of the geostationary arc for a ground terminal in the contiguous United States.