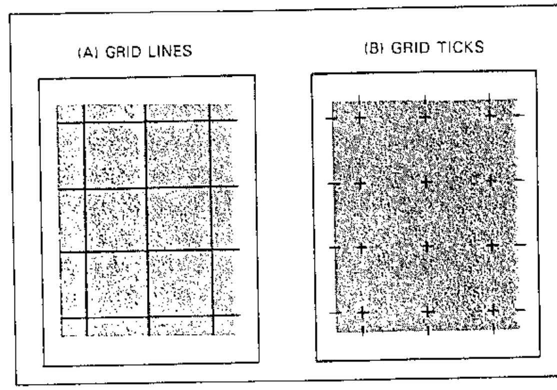
Plane Coordinates

As we've seen, we face many problems when we use the geographical grid to locate point features. We can trace most of these difficulties to the fact that the latitude-longitude system is based on the structure of **spherical coordinates**. In other words, it uses coordinates that show position on a rounded surface. Obviously, it would be much simpler if we could designate location on a flat surface using **plane coordinates**. We could then simply read coordinates from a square grid of intersecting straight lines.

To devise such a system, we would have to deal somehow with earth curvature. We know that transferring something round to something flat always causes distortion. But we also know that map projection distortion due to earth rotundity is minimal for fairly small regions. If we superimpose a square grid onto flat maps of small areas, therefore, we can achieve spatial reference accuracy for many purposes. We can also avoid the frustration of using inconvenient latitude-longitude notation.

A major issue with plane coordinate systems is the choice of origin for the grid. On large-scale maps intended for local use, the origin is often chosen arbitrarily to suit the available map format. For maps in a series, and for maps intended to be used with other maps, it's common to tie the origin to the ground, creating a terrestrial reference system. Let's look first at arbitrary local grids, and then we'll discuss some examples of terrestrial systems.



11.3 The geographical grid is shown on maps published by the U.S. Geological Survey either by grid lines (A) or grid ticks (B).

Arbitrary Local Grids. When an arbitrary square grid of reference lines is superimposed on mapped features, it's called a **local grid**. A flat map has only two dimensions—width (left to right) and length (top to bottom). If we superimpose a plane grid on the map, with division left to right labeled as x-coordinates and division top to bottom labeled as y-coordinates, we have established the familiar **cartesian coordinate system (Figure 11.4)**. We can now pinpoint any location on the map precisely and objectively by giving its two numbered coordinates (x, y).

Such a simple way of showing position has a great convenience advantage over the geographical grid. Local grids are especially handy in the laboratory for such analytical procedures as locating environmental features and finding the distance or direction between them.

When we use local grid coordinates, however, we face some special challenges. One problem arises because there's no single logical origin—or zero point—for such a system. Since the earth's surface doesn't provide any natural origin, the map maker's choice is arbitrary. Thus, almost as many different origins are used as there are coordinate schemes. One consequence of using more than one origin is that the precise numerical values of coordinates may vary from one map to the next.

Another problem with using local grids is that field use is limited unless you have a GPS receiver that allows entry of a user-defined grid (see Chapter 15: *GPS and Maps*). If you have such a receiver and take the time to customize it to your local map grid, you can put the local coordinate information to practical use.

State Plane Coordinates (SPC). The SPC system overcomes many problems associated with arbitrary local grids. It does so because it is a terrestrial reference system—an official standardized system that is tied systematically to the ground.

The SPC system was created in the 1930s to serve several purposes. First, it would completely cover the United States with a flat grid network at a constant scale. Second, maximum scale distortion error wouldn't exceed one in 10,000 (100 parts per million). Thus, distance measured over a

10,000-foot course would be accurate within a foot of the true measure. This level of accuracy couldn't be achieved if only one grid enveloped the whole country; the area is too large. The solution was to divide the United States into a minimum number of smaller zones and make a separate grid for each zone.

The country was eventually broken into 125 zones, each having its own projection surface (see Appendix C for a discussion of map projections). Most states have several zones, as **Figure 11.5** shows. A section from a Lambert conformal projection was used for states of predominantly east-west extent, and a transverse Mercator projection was used for states of mainly north-south extent. This explains the orientation of the individual zones.

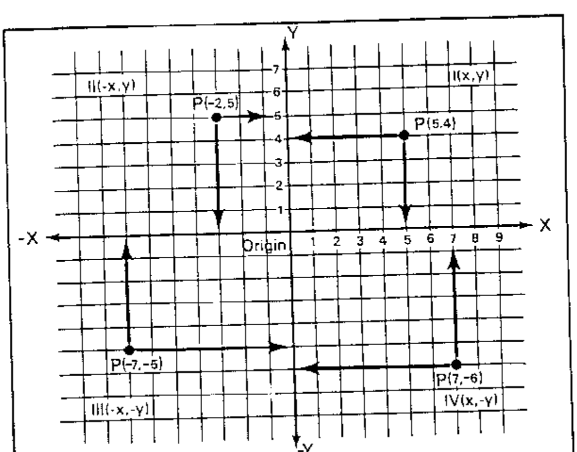
The logic of SPC is quite simple. Zone boundaries follow state and county boundaries. Each zone has its own centrally located **origin**, through which passes its own **central meridian**. A false origin is established to the west and south of the zone, usually 2,000,000 feet west of the central meridian. In the case of Wisconsin in **Figure 11.6**, the Lambert conic projection provides the base for each of the three zones (north, central, and south). You read coordinates first to the east of the false origin and then to the north of the false origin, giving rise to the terms **false eastings** and **false northings**. Since north is conventionally at the top of the map, it may be helpful to remember that you read coordinates **right-up**. Specifically, the correct form of SPC notation is to give the false easting in feet, the false northing in feet, the state, and the zone. For example, you would give the location of the state capitol dome in Madison, Wisconsin, in abbreviated form as:

2,164,606 feet E; 392,285 feet N; Wisconsin, S.

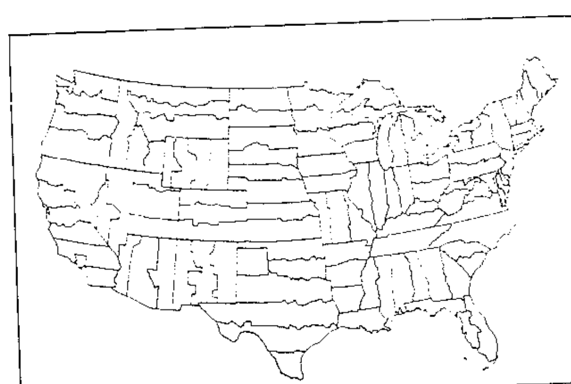
State Plane Coordinates have been widely used for public works and land surveys. Although a full SPC grid isn't superimposed on many maps, 10,000-foot grid lines are indicated by black ticks along the margin of recent USGS quadrangles of the topographic, orthophotoquad, and orthophotomap series.

While the SPC system served the needs of the states when it was created and is still a convenience for the casual map user, it is now largely obsolete as far as surveyors and other professional map users are concerned. One reason is that accuracy of 100 parts per million (one in 10,000) in locating points is now easily achieved using modern surveying methods. Also, each SPC zone is a separate entity with its own defining characteristics—a fact that frustrates and discourages joint operations across zone boundaries.

You may find the SPC grid useful for analyzing maps in the laboratory. For field use, you can enter key SPC map parameters into your GPS receiver as a user-defined grid (see Chapter 15: *GPS and Maps*).



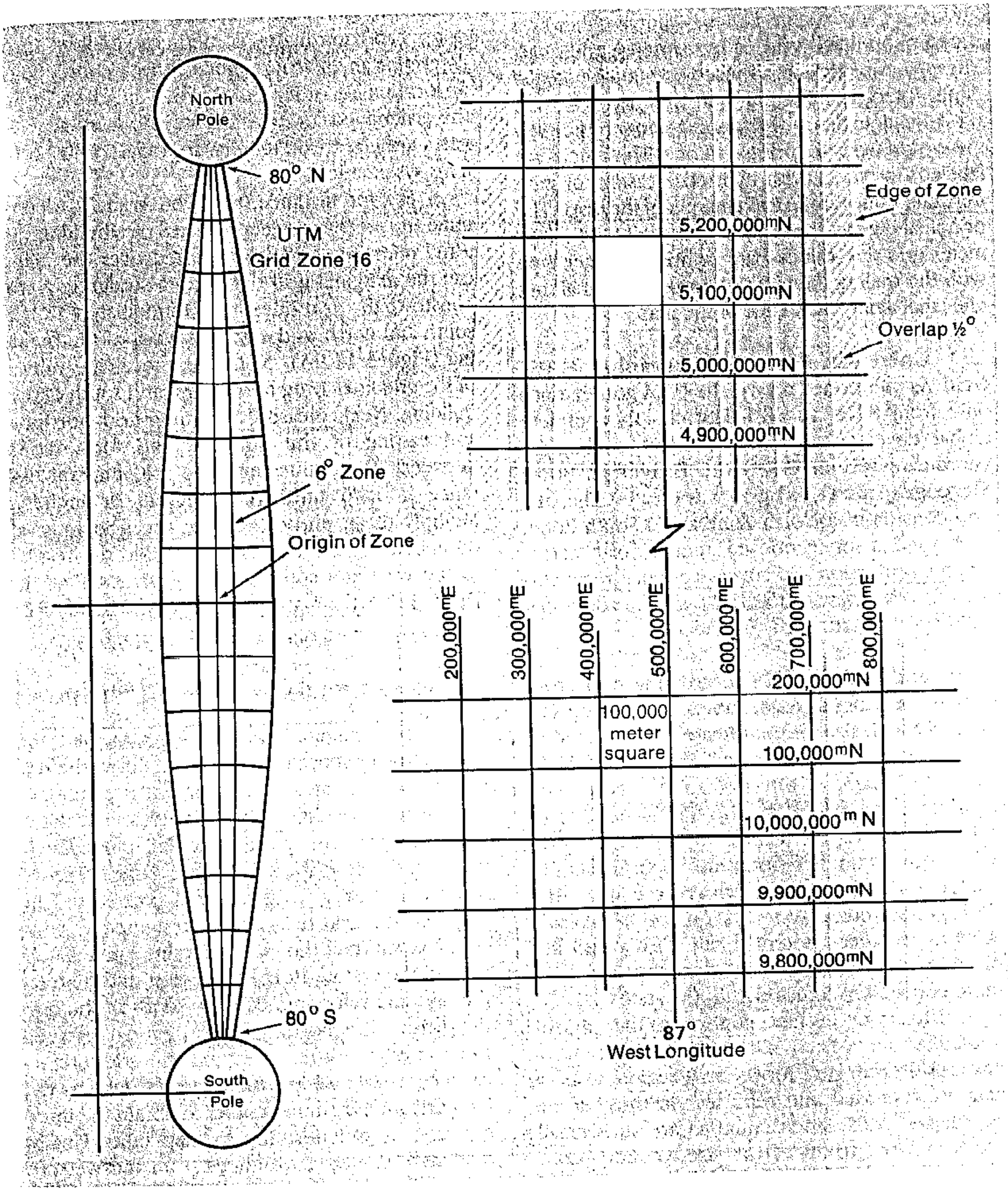
11.4 The structure of the cartesian coordinate system, including basic notation. Notice the different signs of the x and y coordinates in the four quadrants.



11.5 Zones of the State Plane Coordinate System for the contiguous United States. Notice that the zones are oriented either north-south or east-west, depending on the shape of the state.

This means that every location on the equator has two sets of grid coordinates. For example, the coordinates for the zone origin are:

500,000^{m}E, 0^{m}N in the northern half
and
500,000^{m}E, 10,000,000^{m}N in the southern half.



11.8 The Universal Transverse Mercator grid is shown here for selected portions of zone 16.

Universal Transverse Mercator (UTM) Grid. The convenience of a flat grid can also be enjoyed at the global level if enough zones are used to ensure reasonable accuracy. Probably the best known plane coordinate system of international scope is the **Universal Transverse Mercator (UTM)** grid. All vendors program its specifications into their GPS receivers.

The UTM grid extends around the world from 84° North to 80° South. Sixty north-south zones are used. Each one covers six degrees of longitude, with an overlap of 30 minutes with the zones on either side (**Figure 11.7**). A section from a transverse Mercator projection is used to develop a separate grid for each of the 60 zones. This method makes it possible (assuming a constant scale) to achieve an accuracy level of one part in 2,500 maximum error within the zone.

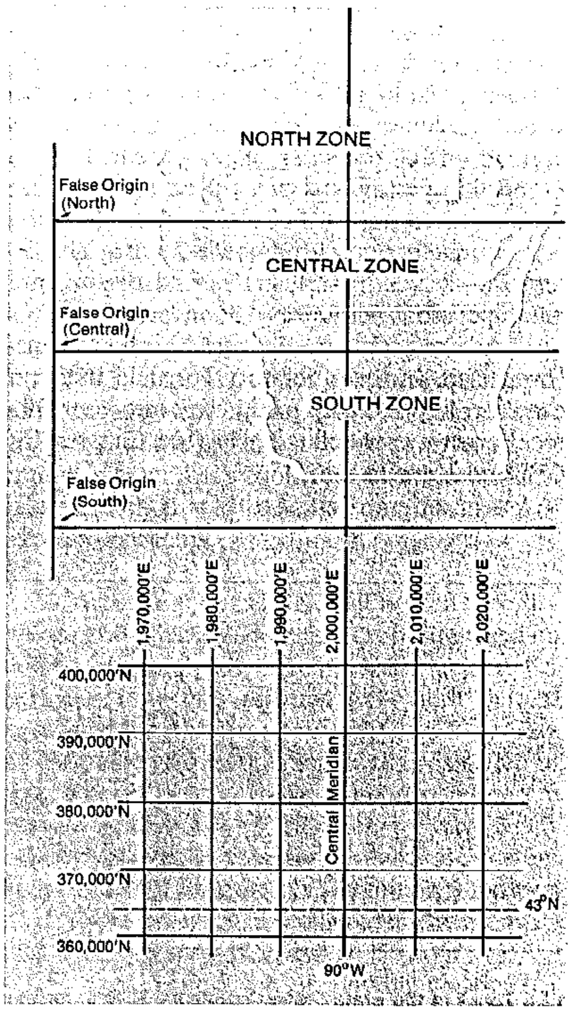
The logic of the UTM grid is similar to that of SPC. Each zone is individually numbered from west to east, beginning at the 180° meridian. Each zone has its own origin, located at the intersection of the equator, and its own central meridian (**Figure 11.8**). A false origin for the north half of the zone lies on the equator 500,000 meters west of the origin, and a false origin for the south half of the zone lies 500,000 meters west and 10,000,000 meters south of the origin (or 10,000,000 meters directly south of the false origin for the north half of the zone). You read coordinates as for SPC—first to the east and then to the north of the appropriate false origin. You give the false easting in meters, the false northing in meters, the zone number, and the zone hemisphere (north or south). Thus, you would designate the location of the capitol dome in Madison, Wisconsin, in abbreviated form as:

305,904 meters E; 4,771,651 meters N; 16, N.

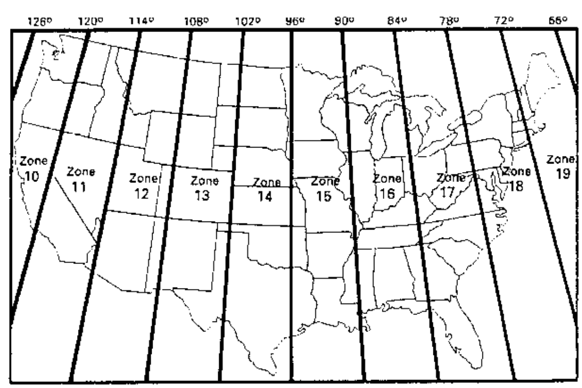
Because UTM zones are formatted according to the geographical grid and not state boundaries, it usually takes more than one UTM zone to cover a state completely. Wisconsin falls into two zones: 15 and 16 (see Figure 11.7).

It's also of special interest that the equator has two false northings:

0$^{m\ (meters)}$N in the northern half
and
10,000,000^{m}N in the southern half.



11.6 State Plane Coordinate zones and notation for Wisconsin.



11.7 Zones of the Universal Transverse Mercator grid in the contiguous United States.

The near universal scope of the UTM grid makes it a valuable point referencing system. The UTM grid is indicated on many foreign maps and on all recent USGS quadrangles in the topographic, orthophotoquad, and orthophotomap series. The position of selected grid lines is shown either by a superimposed full grid or by marginal grid ticks. These lines or ticks are spaced at 1,000 or 10,000 meter intervals, depending on the map scale. On USGS quadrangles of the topographic series, 1,000-meter grid ticks are printed in blue. These ticks are labeled (in black) with their false easting or false northing values along each margin of the map. The principal digits—those which represent the 1,000-meter grid tick values—are printed in larger type with the trailing digits (000) dropped from all but one label along each edge of the map.

Universal Polar Stereographic (UPS) Grid. As mentioned above, the UTM grid extends only from 84°N to 80°S latitude. To complete global coverage, a complementary rectangular coordinate system called the **Universal Polar Stereographic (UPS)** grid was created. The UPS grid consists of a North Zone and a South Zone. Each zone is superimposed upon a polar stereographic projection and covers a circular region. To provide overlap with the UTM grid, an additional half degree of latitude is provided.

Modified Grids. The growing popularity of digital methods in all phases of mapping has kindled the desire for coordinate grids tailored to specific needs. States that fall into several UTM zones, for example, often create a special state coordinate grid by shifting the central meridian of a UTM zone to the center of the state. Thus, Wisconsin routinely records and reports data formatted in the **Wisconsin Transverse Mercator (WTM)** coordinate system. UTM and WTM have the same accuracy potential, but WTM avoids the problem of having two UTM zones. Thus, it's more convenient to use within the state.

Even counties have gotten into the spirit of grid adjustments. Each of Wisconsin's 72 counties has a grid optimized for its own region. County data are recorded and reported on these plane coordinate grids. Since counties are such small regions relative to the earth's size, a county-based plane grid can provide extremely accurate spatial referencing.

Coordinate Determination and Plotting

Although the structure of map coordinate systems is relatively easy to understand, it may take practice to gain skill in solving spatial problems using map coordinates. Sometimes you'll want to determine an environmental feature's coordinates or location. At other times you'll need to know the ground position of a feature whose coordinates are given. You should approach both problems systematically.

Say, for instance, that you want to determine the rectangular coordinates of a building. If a full reference grid isn't printed over the map, use the marginal grid ticks and a straightedge to construct the grid lines lying immediately to the south and north, and east and west, of the building (**Figure 11.9A**). Note the coordinate values of the grid lines lying to the west and south of the building. Next, measure the inter-grid northing and easting of the building, and form ratios between these values and the grid interval distance in map units (centimeters or inches). Multiply these proportions by the grid interval distance in coordinate units, and add the results to the west and south grid line values. Thus, in Figure 11.9A, the map reference of the building is:

$$\text{easting} = 305{,}000^{m} + 903.6^{m} = 305{,}903.6^{m}$$

and

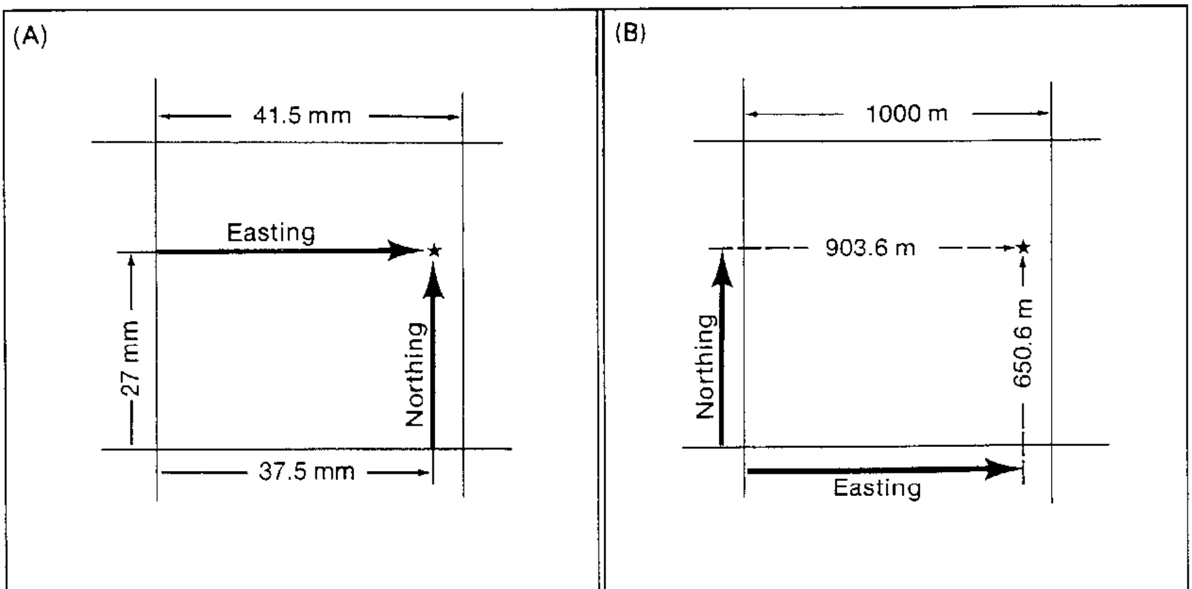
$$\text{northing} = 4{,}771{,}000^{m} + 650.6^{m} = 4{,}771{,}650.6^{m}.$$

Now imagine that you want to plot the location of a feature for which you know the rectangular coordinates. This problem is essentially the reverse of reading map references. First, determine the grid line values that fall immediately above and below the coordinate values (**Figure 11.9B**). If these grid lines aren't plotted on the map, use the grid ticks and a straightedge to do so. Next, subtract the grid line value immediately west of the easting from the easting, and subtract the grid line value immediately south of the northing from the northing. Form ratios between these inter-grid differences and the grid interval distance. Now multiply these proportions by the inter-grid interval in map units to obtain the inter-grid easting and northing in map units. Finally, plot these inter-grid distances from the western and southern grid lines. The two plotted lines will intersect at the desired coordinate location.

If you'll be working with a single coordinate system on maps of a certain scale over and over, it may pay to construct a simple computational aid called a **roamer**.* You can make this graphic device using the right-angle corner of an ordinary sheet of paper, although you may wish to use more durable material. To construct a roamer, merely mark off the grid interval distance along each edge of the paper, starting at the corner. Then divide these distances into units fine enough to suit your map reference needs. Millimeters or tenths of inches should suffice.

By aligning the roamer with the north-south and east-west grid lines, you can determine map references and plot coordinate locations

**Many map-scale and grid-using aids are available commercially. These clear plastic devices have calibrated rulers etched into their surface. The rulers match standard topographic map formats. Check your local map specialty store to get one of these handy ready-made products.*



(A)

EASTING

$\frac{37.5\text{ mm}}{41.5\text{ mm}} = .9036$

$\times$ 1000 m = 903.6

305,000.0 m (West grid line)
+ 903.6 m (Intergrid easting)
305,903.6 m Easting

NORTHING

$\frac{27\text{ mm}}{41.5\text{ mm}} = .6506$

$\times$ 1000 m = 650.6 m

4,771,000.0 m (South grid line)
+ 650.6 m (Intergrid northing)
4,771,650.6 m Northing

(B)

EASTING

305,903.6 m (Easting)
- 305,000.0 m (West grid line)
903.6 m (Intergrid easting)

$\frac{903.6\text{ m}}{1000.0\text{ m}} = .9036$

$\times$ 41.5 mm = 37.5 mm

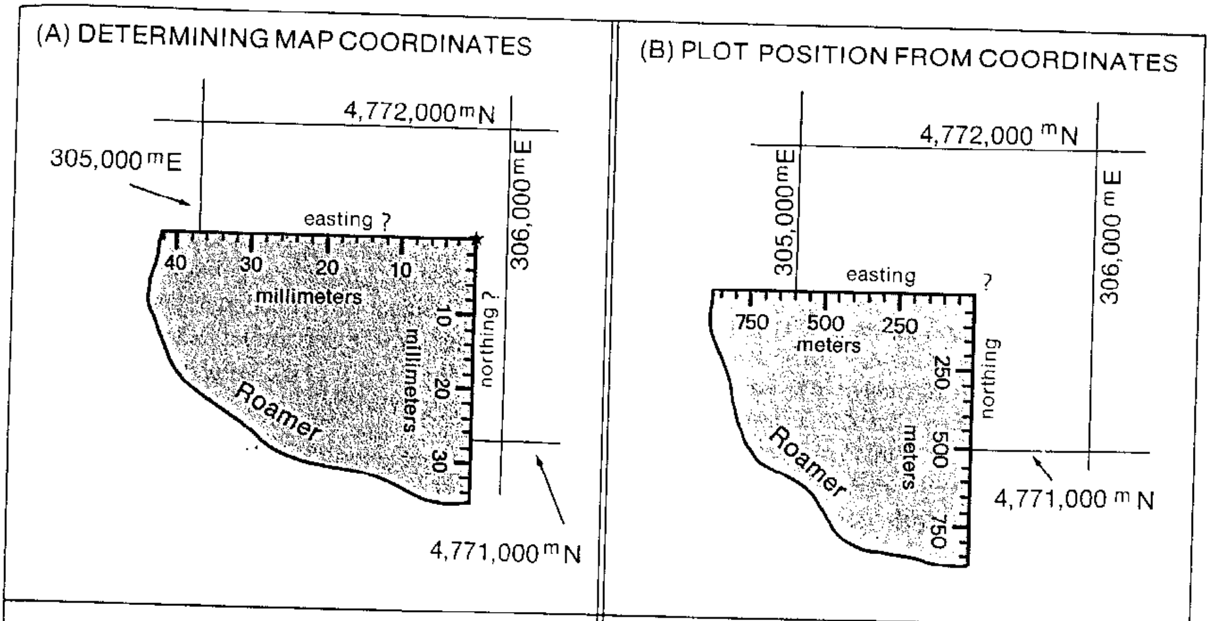
NORTHING

4,771,650.6 m
- 4,771,000.0 m
650.6 m

$\frac{650.6\text{ m}}{1000.0\text{ m}} = .6506$

$\times$ 41.5 mm = 27 mm

11.9 To determine the UTM coordinates of the Wisconsin state capitol dome, follow the steps outlined in A. To plot the dome's location from UTM coordinates, follow the procedure in B.



PROBLEM: Determine UTM coordinates of building.
Step 1: Align roamer so that its edges are parallel with the grid lines and its corner is positioned at the center of the building.
Step 2: Read the intergrid easting and intergrid northing from the edges of the roamer.
Step 3: Add the intergrid easting and intergrid northing to the west and east grid line values, respectively.
RESULT: [305,903mE, 4,771,650mN]

PROBLEM: Plot the location of the building with UTM coordinates (305,600mE, 4,771,500mN).
Step 1: Determine the intergrid easting and northing by subtracting the value of the west and south grid lines from the easting and northing, respectively.
Step 2: Slide the roamer across the map to the point where its edge scales provide the proper intergrid easting and northing.
Step 3: Mark the map at the corner of the roamer. This is the plotted position.

11.10 You can use a roamer to determine rectangular coordinates for a feature (A) or to plot a feature's position from known coordinates (B).

teur (HAM) radio operators.* This terrestrial reference scheme is based on the **Maidenhead** global system, which partitions the earth into progressively smaller quadrilaterals of latitude and longitude. The first two letters in the reference divide the earth into 20° by 10° fields. Pairs of numbers designate 2° by 1° squares within these fields. Two more letters are used to define 5' by 2.5' sub-squares within each square. Thus a six-character code can locate any place on earth within a rectangular zone of up to 5½ by 3 miles.

Grid locator maps are available from the Headquarters of the American Radio Relay League, 225 Main Street, Newington, CT 06111.

As with the Page and Grid™ scheme, Trimble has extended the Maidenhead grid so that it provides more precise spatial referencing. This extension makes the grid more suitable for use with their GPS receivers. The extension, called the *Trimble Grid Locator*™, adds a pair of numbers and a pair of letters to the six-character Maidenhead code.

Military Grid

Another terrestrial reference scheme is the **U.S. Military Grid Reference System**. It is used with UTM and UPS grids. In devising this system, the military aimed to minimize confusion when using long numerical coordinates (up to 15 digits may be required) and numerical zone specifica-