TRACKING THE WILD PRESELECTOR

IN ITS NATIVE HABITAT - THE 7L18

All Tektronix Spectrum Analyzers utilize the superhetrodyne, or mixing, principle. The general equation for the output of a mixer is $M*f_s + N*f_1 = f_{if}$, where f_s is the signal frequency, f_1 is the local oscillator frequency, f_{if} is the intermediate, or IF, frequency, and M and N are positive or negative integers. In most uses, M and N are +1 or -1. For example, in the 7L12 and 7L13, M = -1 and N = 1: $f_{if} = f_1 - f_s$. However, because the 7L18 is such a wide-range analyzer - to 60 GHz -- and because the local oscillator tunes only 2 GHz to 4 GHz on the fundamental (N = 1), we must use oscillator harmonics to cover this range. F_{if}, the first IF frequency in the 7L18 is 510 MHz. The band structure of the 7L18 is shown below.

Band #	Frequency Coverage	N	M	
1	1.49 - 3.49 GHz	1	-1	
2	2.51 - 4.51 GHz	-1	1	
3	3.49 - 7.49 GHz	2	-1	
4	6.51 - 12.51 GHz	-3	1	
5	9.49 - 18 GHz	5	-1	This band stops 18 GHz because the preselector not tune any hi[illegible] For this M and [illegible] the band would [illegible] 19.49 GHz other[illegible]
6	12.51 - 24.51 GHz	-6	1	
7	14.51 - 28.51 GHz	-7	1	
8	16.51 - 32.52 GHz	-8	1	
9	18.51 - 36.51 GHz	-9	1	
10	20.51 - 40.51 GHz	-10	1	
11	30.51 - 60.51 GHz	-15	1	

Bands 1 - 5 utilize the preselector and the main front panel input, while bands 6 - 10 make use of external waveguide mixers (sold seperately). The local oscillator goes out to the mixer, and the IF comes back to the analyzer at 510 MHz, through the external mixer port on the front panel. For most of the waveguide bands, a single waveguide mixer will not cover the full frequency range shown.

In general, with inputs of f_s and f_1, the mixer will produce outputs corresponding to a number of values of N. Unless f_s is unusually storng, only M = +1 and -1 will produce outputs. The frequency selectivity associated with the IF amplifier will select only the output or outputs at the desired IF frequency. The loss of the mixer increases as N increases. (Loss = power input at f_s/power output at f_{if}, expressed in dB. The ratio is written this way because, for a gain of less than 1, we want the loss to be a positive number.)

The value of the loss for any given N can be minimized by choosing the proper bias current for the mixer. The desired bias varies with the value of N. For this reason, there is a seperate internal mixer bias adjustment for each preselected band. When using waveguide mixers, the proper bias depends on the particular mixer used, so the bias is adjustable with the front panel PEAKING control in the waveguide bands. The bias is applied to the mixers through the IF ports. Hence, a DC block should always be used when connecting any test equipment to the input ports of the IF amplifier (or the external mixer port on the front panel.)

In addition to adjusting the bias, we must adjust the sweep applied to the oscillator to correspond to the harmonic number, N. The effective local oscillator frequency is $N*f_1$. Similarly, the effective sweep range of the oscillator is $N*\Delta f$, where Δf is the sweep range of the fundamental oscillator output. For a span/division setting of f_{span} MHz, the oscillator must be swept f_{span} MHz/division. The necessary attenuation of the sweep is done in the span attenuator, based on the code read from the band switch. Also, there is an IF gain adjustment for each preselected band so that the increasing mixer loss can be compensated, maintaining a constant reference level.

WHY THE 7L18 HAS A PRESELECTOR

Although a given mixer bias may be optimum for only a particular value of N, mixing products due to other values of N will occur simultaneously. For example, in the 7L12 and 7L13, the first IF is at 2.095 GHz. When the local oscillator is turned to 3.0 GHz, a signal at 905 MHz will convert according to the equation $f_1 - f_x = f_{if}$. However, if 5.095 GHz were present at the mixer, it would convert according to $f_s - f_1 = f_{if}$. A 3.905 GHz signal would convert by $2*f_1 - f_s = f_{if}$. Any signals present at the analyzer input at these frequencies, however, are blocked from the mixer by the input low-pass filter which attenuates frequencies above 1.8 GHz, the maximum frequency of the instrument. In fact, for signal levels at which M = 1 or -1, all undesired spurious response occur at signal frequencies greater than the maximum input frequency of the analyzer. This is so because the first IF frequency is also greater than the maximum input frequency. In the 7L18, however, this is not the case. With a local oscillator frequency of 3 GHz, signals of 2.49 GHz, 3.52 GHz, 5.49 GHz, or 6.51 GHz -- to list only a few -- will all produce outputs at 510 MHz, the IF frequency.

The preselector is a tunable filter which passes only frequencies within a narrow bandwidth on each side of the frequency which will mix with the local oscillator according to the desired conversion. Frequencies which would convert in a spurious manner are blocked. The preselector width is about 20 MHz at the low end (1.5 GHz) and 40 to 50 MHz at the high end (18 GHz). The preselector is swept along with the oscillator.

In the waveguide bands, there is no selectivity in the front end. As a result, all conversions appear on the screen. The only change made on the instrument as it is switched between bands is the changing of sweep width to correspond to the harmonic number for each band. Hence if we had two signals, we would know that we were on the correct band when the seperation between them was correct. The equivalent of two signals is provided by two different conversions of the singal: $N*f_{1a} - f_s = 510$ MHz $f_s - N*f_{1b} = 510$ MHz. The frequencies $N*f_{1a}$ and $N*f_{1b}$ are 1020 MHz apart. The IDENTIFY position of the SPAN knob provides a span of 510 MHz/division. When the BAND switch is set correctly for the harmonic N in use, these two frequencies, and the two signals on screen, will be two divisions apart.

THE INNER WORKINGS OF A PRESELECTOR

A bandpass filter can be viewed as a series of resonators at the center frequency of the filter. The bandwidth and shape of the filter depend upon the number of resonators, or "poles", in the filter. As the number of poles increses, the bandwidth of the filter decreases, but its loss increases.

In the preselector, the resonators are spheres of YIG (Yittrium-Iron-

Garnet) material. There are three spheres in the filter. The RF energy is coupled into and out of the filter via loop coupling. The YIG material is ferromagnetic and the resonance involved is ferromagnetic resonance. The resonance frequency is determined by the value of the magnetic field in which the spheres are located. In the preselector, this field is created by an electromagnet made up of two coils of wire mounted on pole pieces having a gap between them. The YIG spheres comprising the filters are mounted in the gap. See Figure 1. The resonant frequency is directly proportional to field strength, which is directly proportional to current.

The same YIG resonance principle is also used in the 2 GHz to 4 GHz local oscillator.

THE BASIC TRACKING PROBLEM

The tracking equation can be obtained by rearranging the basic mixing equation to get fp, the frequency to which the preselector should be tuned: $f_p = N*f_1 \pm 510$ MHz.

Theoretically, the oscillator and preselector frequencies are directly related to the drive current. Hence, the tracking equation could be written: $I_p = K*N*I_1 \pm I_{510}$, where I_p is the preselector current, I_1 is the oscillator current, I_{510} is the magnitude of the current necessary to move the preselector 510 MHz, and K is a constant which compensates for the different tuning sensitivities (in MHz/ma) of the oscillator and preselector.

The driver system which provides drive current to the oscillator and preselector is shown in block diagram form in Figure 2. At point "A", the voltage is directly proportional to the frequency to which the oscillator

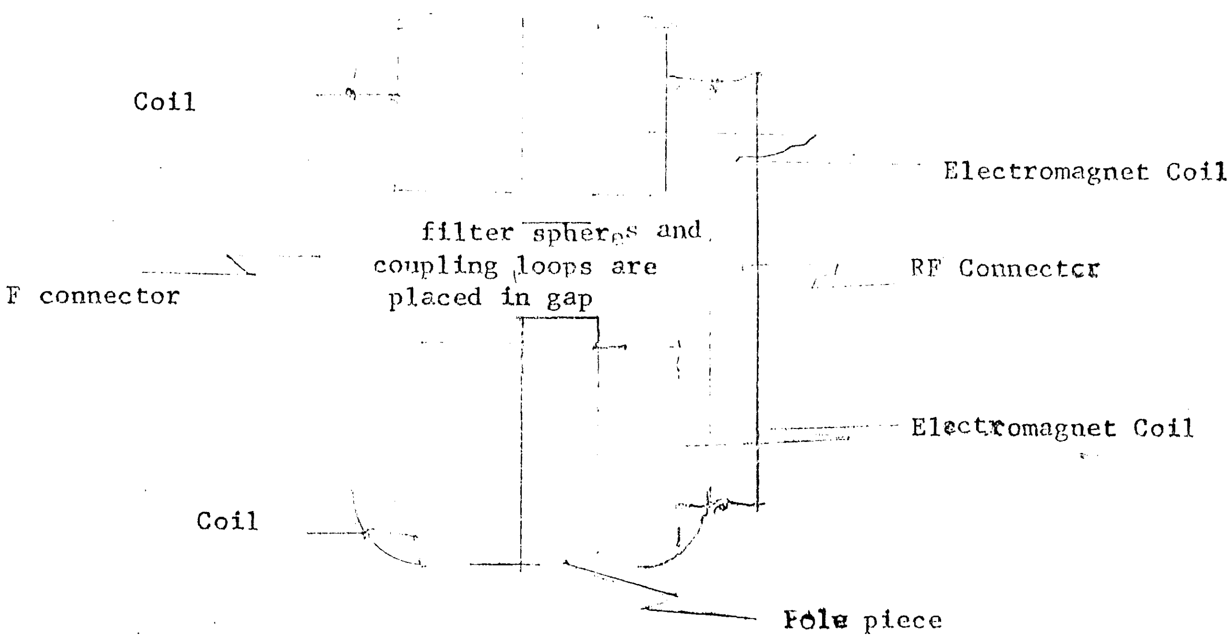

Figure 1. Simplified YIG preselector magnetic structure. Gap length is highly exaggerated. Actual gap length is about 60 mils.

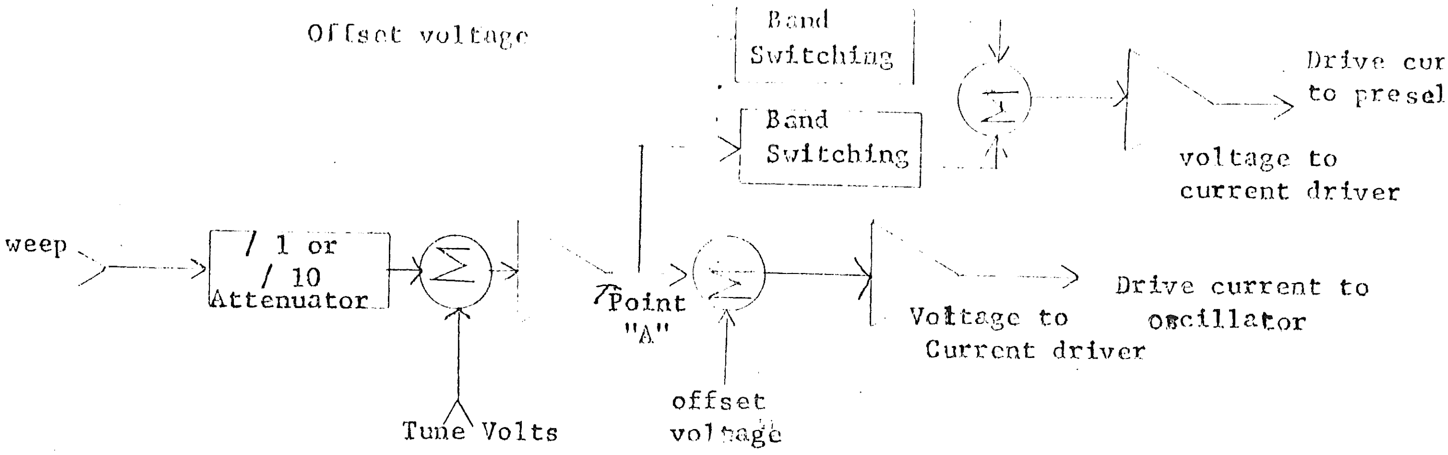

Figure 2 Block diagram of 7L18 Oscillator and Preselector drive system.

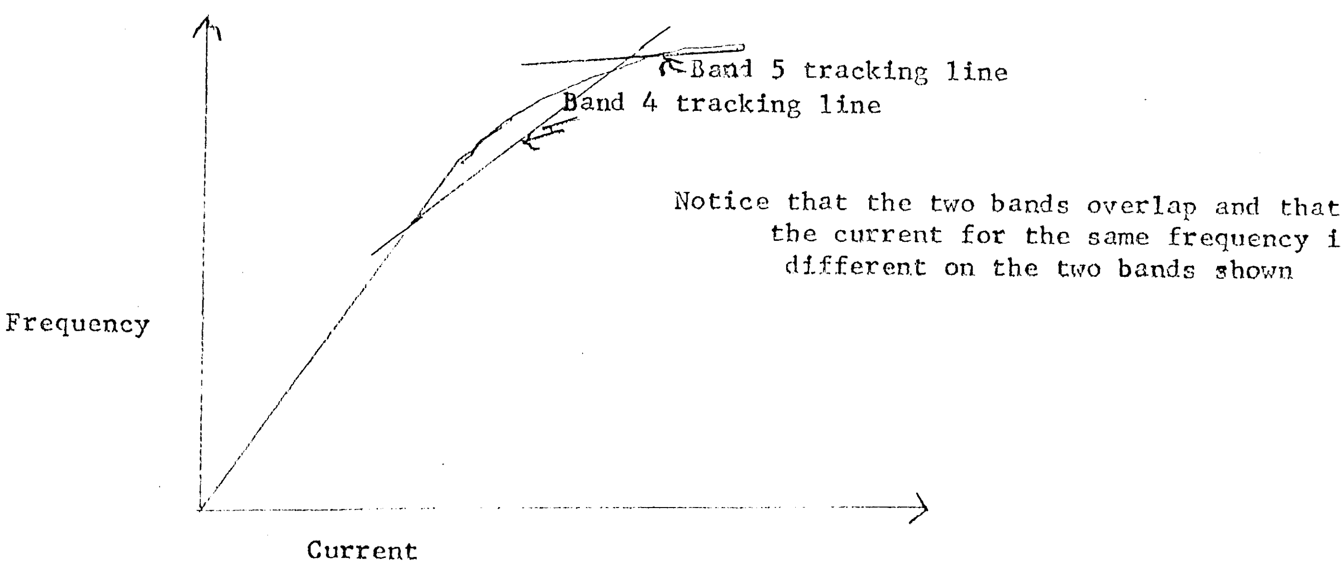

Figure 3 Typical preselector frequency vs. current curve. The nonlinearity of tl curve is exaggerated. Typical lines showing current provided by the driver as function of frequency are also shown for bands 4 and 5.

should be tuned: -10 volts for 2 GHz to +10 volts for 4 GHz. 3 GHz is thus at zero volts. However, because of the direct relationship between oscillator frequency and current, the oscillator requries drive current at 3 GHz. The offset voltage summed into the final driver stage serves to provide the required current when point "A" is at zero volts. Neglecting the different gains for V_B and V_A, we can write $I_1 = K_1 (V_o + V_A)$ or $I_p = K*N*K_1 (V_o + V_A) \pm I_{510}$. We can rearrange this formula to get: $I_p = N*K_2*V_A + (N*K_2V_o \pm I_{510})$. The two terms in this formula correspond to the two signals summed to provide the preselector drive: one proportional to V_A and one which depends only on the band selected.

The band-switching circuits change the multiplication factor of V_A and do the offset switching. Theoretically, these changes could be done by switching fixed resistors, with only one overall adjustment to compensate for variations in preselector sensetivity due to production tolerance. However, the preselector curve is not exactly linear, especially at high frequencies and high currents. High levels of current produce magnetic saturation of the core material, with the result that the magnetic field does not increase as fast as the current. A typical preselector curve, with the nonlinearity exaggerated, is shown in Figure 3. Regardless of the shape of the curve the driver can only provide a straight-line fit. (This is not entirely true. The driver provides a straight-line voltage versus frequency relationship. The output stage of the driver which converts the voltage to the current drive for the coil can employ some shaping to produce a non-linear output. The original driver was designed to use shaping, but it is not known if this will actually be needed.) We can fit the curve better with several straight lines which each cover a small frequency range than with one overall line. For any given band, the line which fits the curve probably will not be the one indicated by the tracking equation. Hence, the preselector driver includes adjustment controls for both the multiplication factor of V_A (SLOPE) and the offset for each band to allow the tracking on each band to be tailored to the curve of each preselector.

A SIDE NOTE

Because the preselector must track the oscillator, the oscillator adjustments affect the tracking. Therefore, the tracking of an instrument should be done after all other calibration adjustments of the sweep/span system have been completed. However, some of these adjustments require that the instrument be displaying signals. With luck at least one narrow band of frequencies will get through the preselector. If not, RF signals can be input at the external mixer port and will find their way through the couplers in the first converters to the internal mixer in bands 1 through 5. A DC Block and a 20 dB pad should be used between the signal source and the input.

TRACKING ADJUSTMENTS

Ideally, the preselector would be centered, at every instant of the sweep, on the frequency which would mix with the local oscillator frequency at that instant to produce the desired conversion. Because of nonlinearities, this will not occur. Over at least some portion of the band, the preselector will not be centered. How far away from the center we can be and still have "good" tracking depends on the bandwidth of the filter. If for example, at any frequency within 25 MHz of the filter center frequency, the loss through the filter is not greater than 1 dB more than it is at the center, we can be off in tracking by up to 25 MHz without degrading system flatness by more than 1 dB. Fortunately the preselector is wider at the high frequencies where nonlinearities are worse.

Two possible tracking lines, -- for bands 4 and 5 -- are shown in Figure 3. Note that in the frequency range in which the bands overlap, the current for the same frequency is not the same. Hopefully, for all preselectors, the difference between the straight line representing the driver output and the actual curve will be less than the bandwidth of the preselector.

In adjusting the tracking, we would like to have an adjustment procedure in which the two controls for each band do not interact. When V_A is zero volts, the SLOPE adjustment will not affect the driver output. Hence, we can adjust the offset control to peak the signal at the center of the band, at a signal frequency corresponding to an oscillator frequency of 3 GHz. For the various bands, the proper frequencies are:

Band	Frequency
1	2.49 GHz
2	3.51 GHz
3	3.49 GHz
4	9.51 GHz
5	14.49 GHz

After we have this one point adjusted properly, we can adjust the gain to correct value. This is done by moving the input signal away from the center frequency and observing the indication on screen. If the gain value is not correct, the signal amplitude will drop. The gain control is used to peak the signal at the frequencies away from the center and does not affect the tracking at band center.

This would be all the adjustment necessary if the preselector were exactly linear. With nonlinearities, however, we may get best tracking with a different set of adjustments: for example, we may not want the preselector exactly centered at band center. In practice, the first two adjustments as described above have generally brought the preselector in rather well. The main problem has been insufficient range on the adjustments. We are just starting to get enough information on enough preselectors to see how bad the nonlinearities are.

There is also an overall slope adjustment to compensate for the variations between preselectors. Having this seperate adjustment allows the band adjustments to cover a smaller range. The overall adjustments should be set to peak the signal at 18 GHz with the band SLOPE and OFFSET controls set to the center of their range.

In summary, the adjustment procedure is:

1. Set the band 5 slope and offset adjustments to the center of their ranges. Input an 18 GHz signal to the analyzer. Adjust the PRESELECTOR SLOPE adjustment to maximize the signal indication. (In production, we will probably eliminate the overall slope adjustment, Instead, we will use selected fixed resistors based on the preselector current at 18 GHz as measured during preselector manufacture.)

For each band, use the following procedure. Degause the preselector before starting. The PEAKING control should be at midrange. Adjustments should be made in MAX span.

2. Input a signal at band center frequency. Adjust BAND OFFSET adjustment to maximize the signal.

3. Tune the input signal away from the center frequency. Unless extreme luck prevails, the on-screen amplitude of the signal will fall. At the band edge, or before if the signal threatens to fall into the noise, maximize the signal indication with the BAND SOPE control. If the control is adjusted at an intermediate point, continue to the band edge and maximize the signal there also.

4. Check the other side of the band. If the signal is not peaked there also, adjust the BAND SLOPE control to maximize the signal. Go back and forth between the ends of the band, trying to adjust the BAND SLOPE control for the best overall flatness.

5. If the tracking is not too good, try adjusting the BAND OFFSET control to see if best tracking can be obtained with the signal slightly off peak at band center. If this does not help, the tracking is about as good as it can be. If it helps, slightly adjust both the OFFSET and SLOPE controls for best overall tracking.

The above procedure assumes that a sweeper or signal generator is used for the input signal. On the lower bands (1, 2, 3) a comb generator can be used instead. The center and sides of the comb should be adjusted with the OFFSET and SLOPE controls, respectively. On bands 4 and 5, there is a large possibility of tracking on a spurious conversion if a comb is used. Therefore, a comb should not be used unless another method is used to assure that the tracking is approximately right. (See next section.)

In the higher bands, the span in MAX is quite wide, and the resulting slow sweep for calibrated operation may make it hard to peak signals because the visual "feedback" of the results of an adjustment are slow. In such cases, switch to MANUAL SPAN. Set the MANUAL SPAN pot so the signal is displayed and adjust for the peak.

GETTING THERE FROM HERE WITHOUT FALLING INTO A TARPIT

The preselector adjustments are what really determine the band structure of the instrument: for example, on band 5 we can be sure that we are using $5*f_1 - f_s = 510$ MHz as a conversion only because the preselector tracking (when properly adjusted) is set for this conversion. By changing the preselector drive, we could make use of a different conversion, such as $f_s - 5*f_1 = 510$ MHz. Some readouts would be wrong, but the instrument could be tracked . Any conversions would be possible within the range of the oscillator and the preselector. At first turn on, the preselector is usually far out of adjustment. On each band, the adjustment range is limited so that we cannot get to many of the possible spurious conversions. (For example, band 5, we could not set up to track the first harmonic unless there was a wrong component value in the driver.) But we can get to some. In the case of the two band 5 conversions described above, the desired conversion is called the "-" conversion and the other the "+" conversion. When the oscillator is at 3 GHz and we are adjusting the offset, for the "-" conversion, the desired signal frequency is 14.49 GHz. The signal of the frequency of the "+" conversion is 15.51 GHz. It is possible to tune the preselector to either of these two frequencies by adjustment of the OFFSET and overall SLOPE controls. With a comb having lines near both 14.49 and 15.51 GHz, it would be impossible to tell which conversion we were getting. There is also the possibility of setting up on conversions with harmonic numbers other than the desired one.

Spurious conversions can be used as a guide in telling in which direction the preselector should be tuned. For example, suppose the input signal is 14.49 GHz and the on-screen indication is on the right half of the screen, not the center. This could be the "4-" conversion ($f_s - 4*f_1 = 510$ MHz) which for an input frequency of 14.49 GHz requires a local oscillator frequency of 3.495 GHz. For a local oscillator frequency of 3.495 GHz the preselector should be at a higher frequency than 14.49 GHz, namely 16.965 GHz. Hence the preselector needs more current. In the B-0 boards (and probably in production as well), turning the adjustment counterclockwise decreases gain or offset, turning then counterclockwise increases the values. (Increasing BAND OFFSET or OVERALL SLOPE (gain) increases the current to the preselector. Increasing BAND GAIN increases current above the band center and decreases current below band center). In general, if a frequency appears to the right of where it should as the result of spurious conversion, the preselector requires more current; if it appears to the left, the preselector requires less current. Since we are readjusting at band center, we adjust the offset.

A technique which is useful when the preselector is far out of adjustment is to increase the signal power. Some power will get through the preselectin farther from correct tracking and can aid in determining in which direction adjustments should be made. If the on-screen indication does not change in amplitude as the tracking is adjusted, the tracking is far off and the signal is coming through the ultimate attenuation of the filter. Using high signal power increases the number of spurious. (Nothing comes for free.) With high power, we can get values of M (in the conversion equation) with absolute values greater than 1. The most common is M = +2 or -2. The second harmonic of the signal is generated in the mixer just as harmonics of the local oscillator are generated to produce harmonic conversions.

The second harmonic of the signal mixes with twice the desired harmonic number of the oscillator. If the preselector is offset so that $N*f_1 - f_x$ = 255 MHz, then $2*N*f_1 - 2*f_s$ = 510 MHz and we will get a response. The 225 MHz offset is within easy range of the tracking controls. The preselector can be tracked (mistracked) on this response across the entire band. This particular spurious conversion can be recognized by the facts that: 1) the amplitude on screen is around 30 dB less than it should be for the power being input; and 2) When 10 dB of RF attenuation is added, the amplitude will fall by 20 dB.

Some spurs are not as much of a problem on the lower bands as the higher ones. For example, the difference between the "+" and "-" conversions is always 1.02 GHz. On band 1, this is 41% of the desired offset setting of 2.49 GHz, and outside the control range, while on band 5, it is less than 6% of the desired setting and inside the range. If band 1 is tracked first, the settings can be used to "bootstrap" the other bands. The preselector current on any frequency can be measured by either tuning to the frequency and going to zero span or by setting the MANUAL SPAN pot to the desired frequency. Equivalent to reading the preselector current, we can read the voltage across the 5 ohm current sense resistor, R2074. This has the advantage that we don't have to break into the coil circuit to make a series connection for the millameter. We can extrapolate to what the reading should be at another frequency by assuming preselector linearity. For example, if the reading at the center of band 1 is 0.207 volts across the resistor, the reading at the center of band 2 should be 0.207 *(3.51/2.49) = 0.292 volts. If we adjust the BAND 2 OFFSET for 0.292 volts, at band center, we will probably not be exactly on because of preselector non-linearities, but we should be closer to the correct conversion than to any spurious ones. This procedure should be used if a comb generator is used to set up the higher bands. To get sufficient accuracy, a digital meter should be used.

ACTUAL TRACKING PERFORMANCE

We can look at tracking in another way. Ideally, the preselector is centered on the input signal all across each band. In the higher bands, and in the lower bands with some modifications of the driver, we can examine the centering of the preselector at various input frequencies.

Refering again to Figure 2, the voltage at Point "A" which is input to the preselector driver is a summation of sweep and tune voltages. If we could remove the sweep voltage from the preselector, it would remain tuned to the frequency at which the sweep voltage is zero -- that is, the frequency of the center of the screen. We cannot do this when we are sweeping the main coil of the oscillator. However, when we are sweeping FM coil of the oscillators, there is no sweep voltage at Point "A". The sweep voltage is normally provided to the preselector driver through another path and summed with the voltage from "Point "A". We can open this path so that the preselector is not swept at all. As the input frequency is varied, the preselector curve response will be "traced out" on the screen of a storage scope. If the preselector is centered, the preselector curve will be centered on the center of the screen. This technique is more useful in the higher bands because we sweep the FM coil in wider spans than in the lower bands. The widest span in which we sweep the FM coil is 2 MHz/division in bands 1, 2, and 3, 5 MHz/division in band 4, and 10 MHz/division in band 5. At 2 MHz/division, or 20 MHz total sweep, most of the sweep lies within the preselector bandwidth, and the preselector response does not show up. We can, however, modify the driver by providing extra sweep to the oscillator and not the the preselector to use this technique in the lower bands.

Figure 4 illustrates the method. Shown are photographs taken at three frequecies in band 5. The preselector is centered at all frequencies. But if it were not, the photos would tell us which diretion to move and which controls to adjust. Figure 5 is a manufactured example. At the high end and the middle of the band, the preselector is lined up on the peak, but it could be moved lower in frequency (to the left) without the loss increasing, since the top of the response curve is flat. At the bottom end of the band the preselector definitely needs to be moved lower. So we can improve tracking by decreasing the offset to move the preselector lower in frequency over the whole band. If, on the other hand, the preselector had been on at the center, too low at the high end and too high at the low end, we would not adjust offset, but would increase gain.

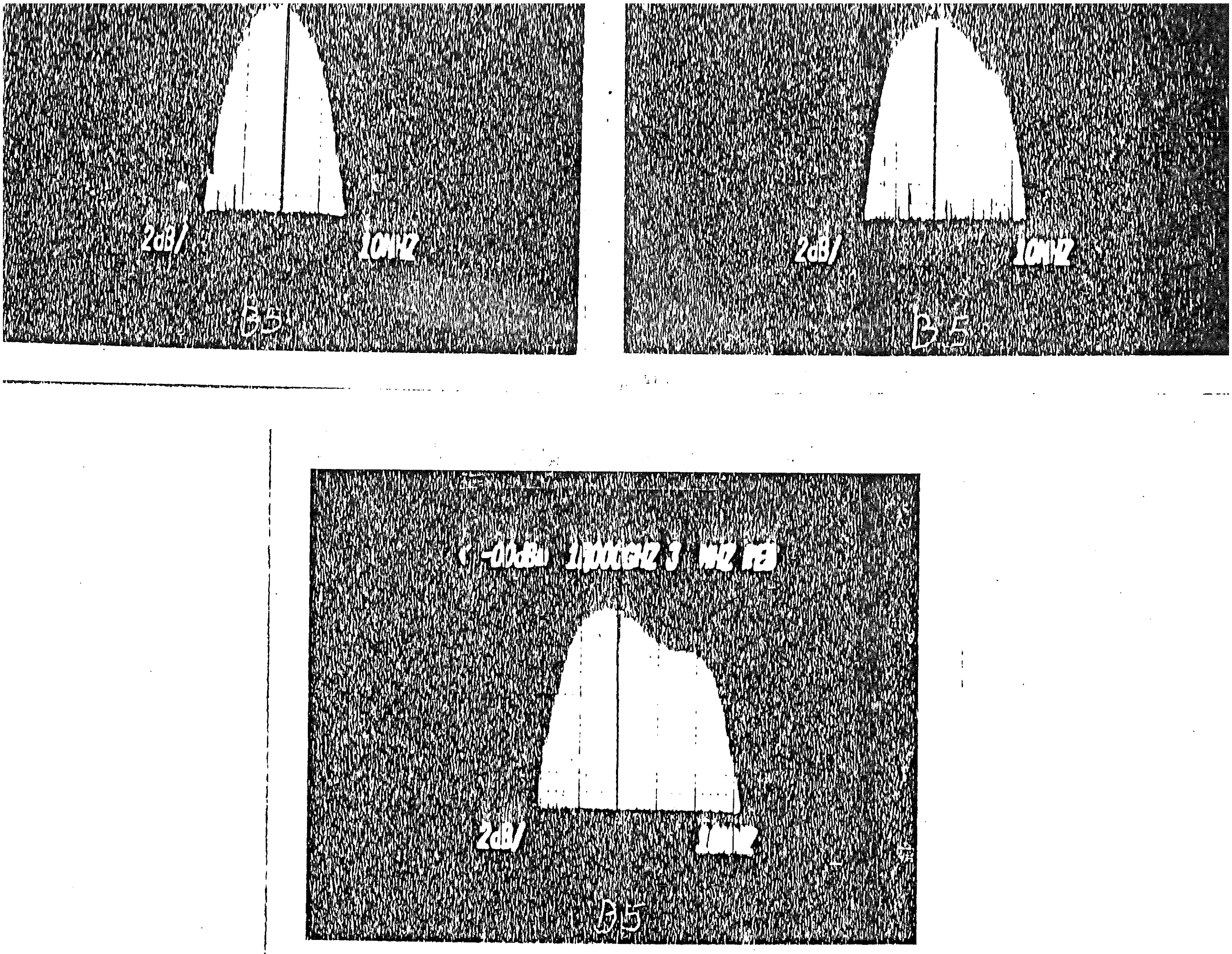

Figure 4. Band 5 Preselector centering photos. These photographs were made by sw
ing the local oscillator and not the preselector. See text for details.
Dark line is center of screen.