COMPLEX MODULATION MEASUREMENTS USING THE SPECTRUM ANALYZER

RF / Wireless Test

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THE SPECTRUM OF MODULATION

- The modulation process modifies some characteristic (such as amplitude or frequency) of a carrier sinewave in accordance with an information bearing signal
- A single sinewave carrier, in theory, occupies zero frequency width
- Modulation, no matter what kind, spreads the spectrum width so that a modulated carrier occupies a bandwidth (BW)
- Occupied, or transmitted, bandwidth shape and width, transmitted power, and various other spectrum characteristics are measured with the spectrum analyzer

USING THE SPECTRUM ANALYZER

TYPES OF MODULATION

- The carrier can be modified in amplitude, frequency, phase, or some combination of these
- The modulating signal can convey information on an analog basis or a digital (pulse code sampled) basis
- Sinusoidal analog modulation, such as ordinary AM or FM, creates a fairly simple to interpret spectrum — digital pulse code phase modulation creates a more complicated to follow spectrum
- In addition to the above, modern modulation systems aim for a high efficiency of spectrum width utilization by transmitting as much information as possible per hertz of BW used — this is done via techniques which are impervious to interference such as CDMA spread spectrum and time sharing of the transmission BW as in TDMA signals
- This creates a very complicated spectrum and involves complex quadrature modulation signals — hence the title of this presentation, "complex modulation"

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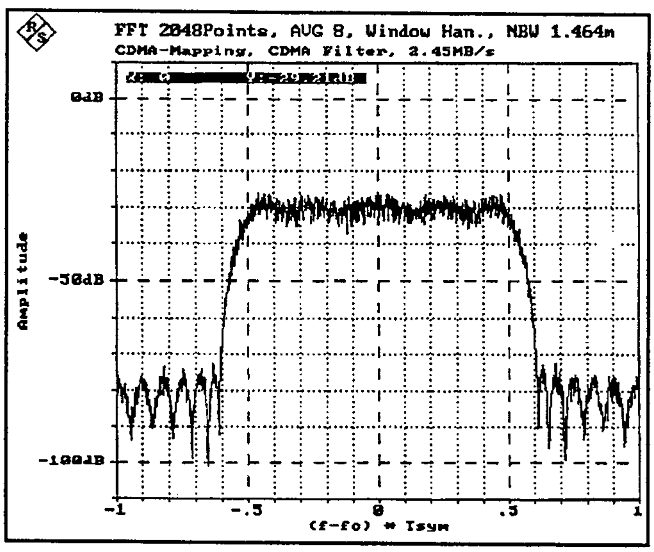
CODE DIVISION MULTIPLE ACCESS — CDMA

- CDMA is a spread spectrum quadrature (I-Q channel) modulation signal that is highly impervious to interference
- It's used in various communication systems such as digital cellular telephony and wireless personal communication
- The figure below is a mathematical computer simulation of the basic CDMA spectrum
- Like all digital complex modulation, the CDMA spectrum appears on the spectrum analyzer as a continuous noise-like power density distribution



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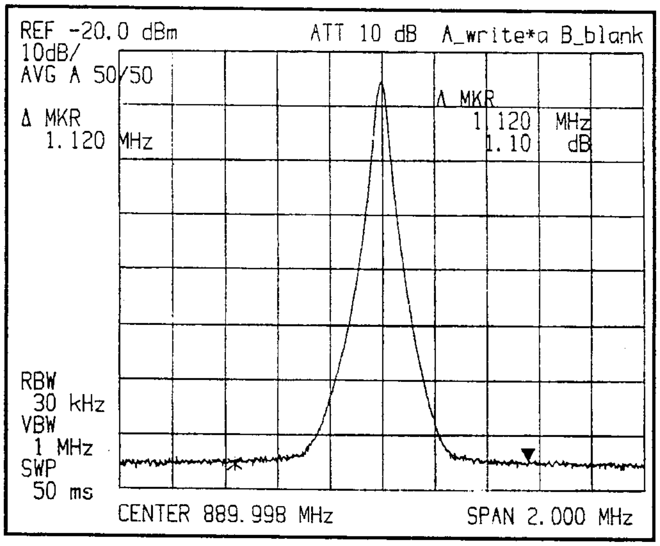
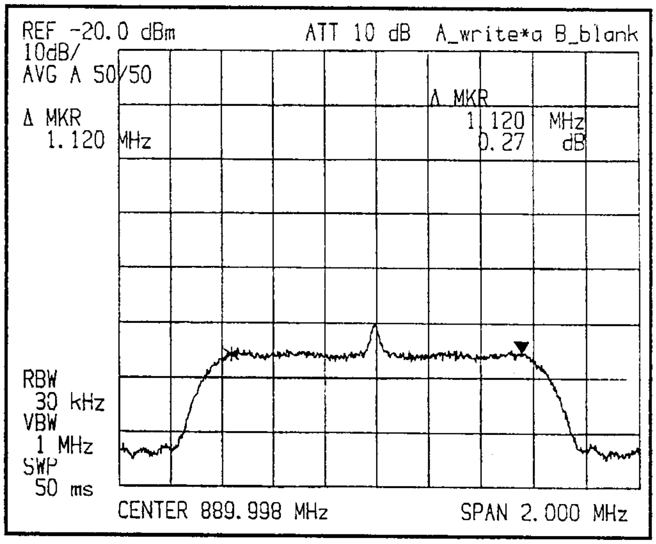
CDMA MODULATED CARRIER

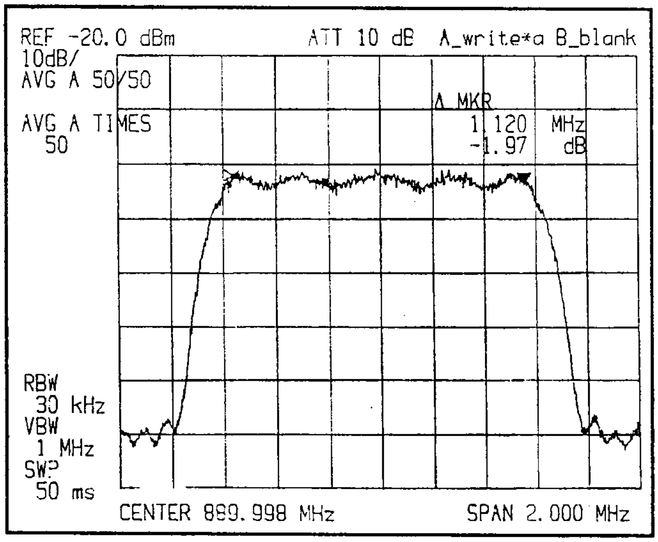
- A sinewave carrier spreads out in frequency when subjected to quadrature I-Q CDMA modulation
- Below are spectra of unmodulated (left) and partially modulated (right) carrier

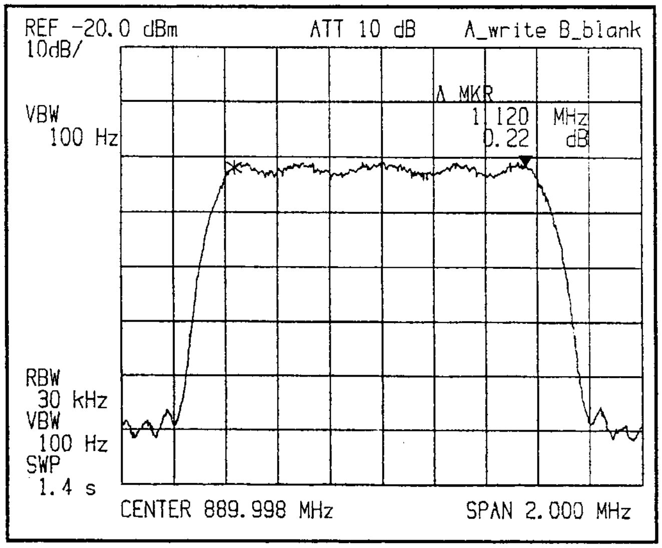




SIGNAL SMOOTHING

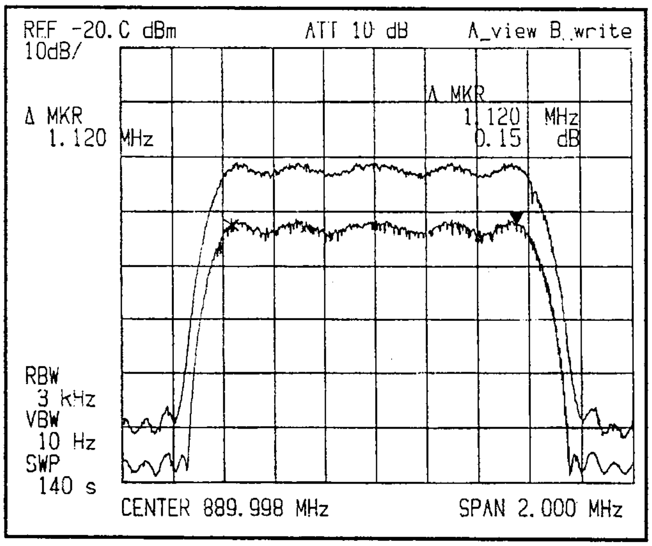
- CDMA, and other complex digital modulation signals, behave as random noise for the spectrum analyzer
- Spectrum smoothing by digital averaging (left) or by narrow video filter averaging (right) will show a clean, noise-like, spectrum shape





AMPLITUDE VS RES BW RATIO

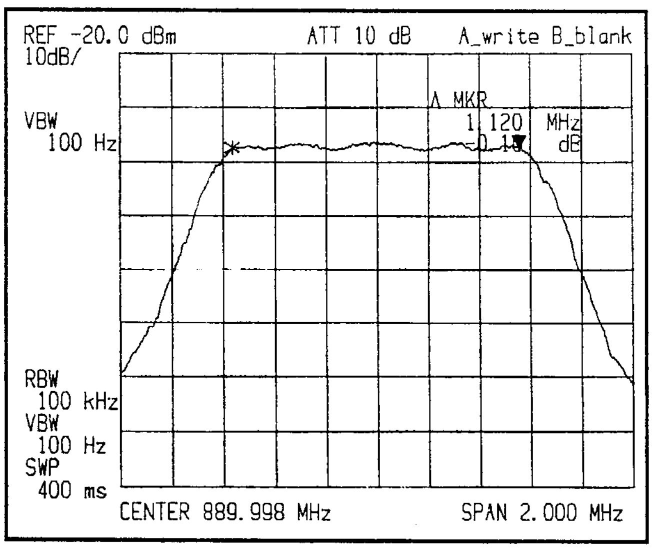
- Like any noise-like spectrum, the CDMA display amplitude varies at 10Log(BW ratio) — a change of 10X from 3 kHz to 30 kHz BW changes the display level by 10 dB



USING THE SPECTRUM ANALYZER

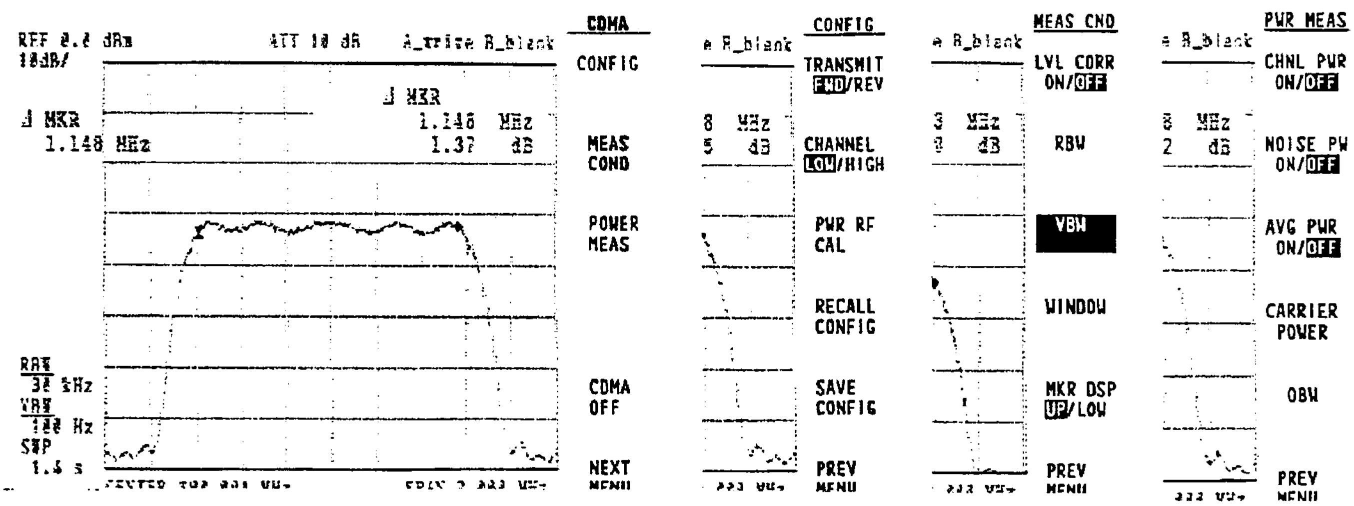
SHAPE DEFINITION VS RES BW

- The usual measurement setting for the classical 1.25 MHz wide CDMA spectrum is at a 30 kHz Res BW
- A very narrow BW results in a much reduced display level at 10Log(BW ratio) — too wide a BW and the true spectrum shape will be lost
- A 100 kHz BW shows the correct CDMA spectrum shape on top but it shows too wide on the bottom



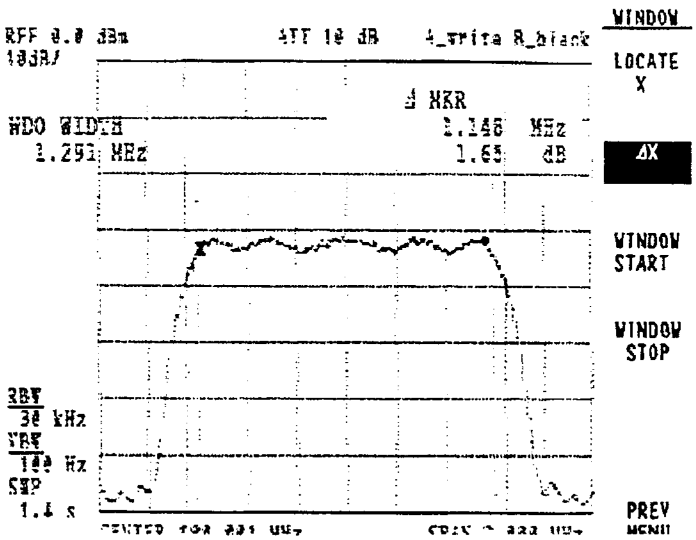
FIRMWARE FEATURES

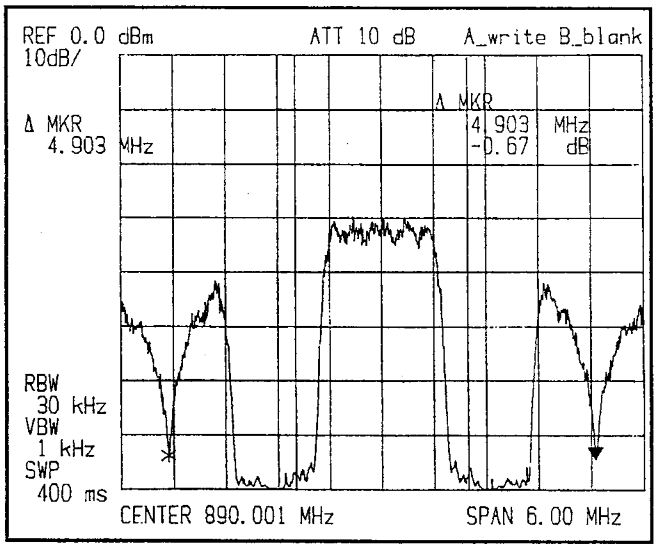
- Some instruments, such as the Advantest R3261C & D, include menu selected firmware for automated complex modulation measurements
- Here's the menu set for CDMA in the R3261C Option 1K (Option 1K includes CDMA modulation accuracy correction factors)



THE WINDOW

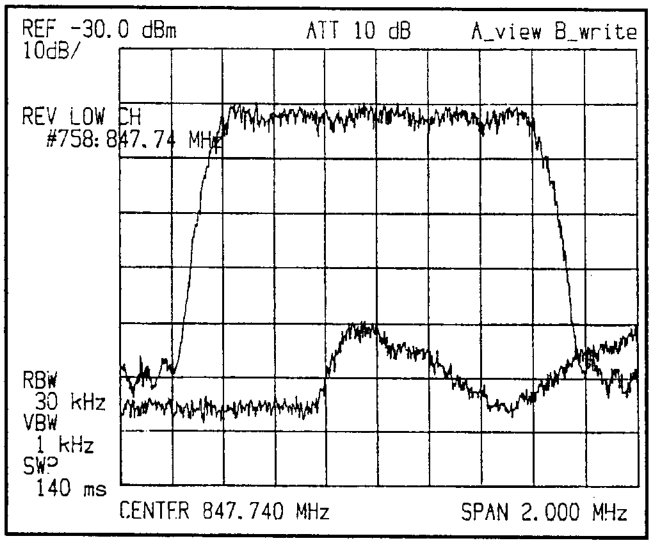
- **The WINDOW function available in CDMA MEAS(urement) CON(dition) menu or as a separate, master, menu is a powerful aid in choosing which spectrum sections are to be measured and which ignored**
- **The WINDOW menu is shown on the left. Using this function is shown on the right**





MEASUREMENT VIA CHANNEL SET MENU

- Menu choices permit a wide variety of measurement choices
- One example from the CONFIG(uration) menu involves automated choice of transmission channel and forward or reverse (reflection) testing
- Below, the reverse (lower channel) spectrum is much smaller than the forward transmission



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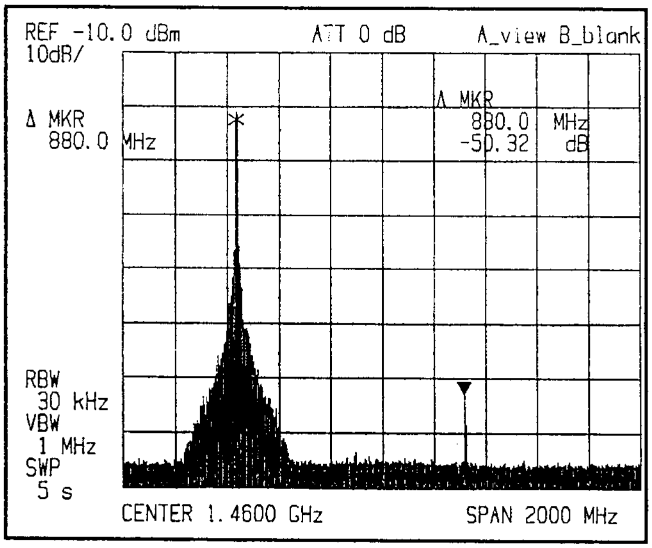
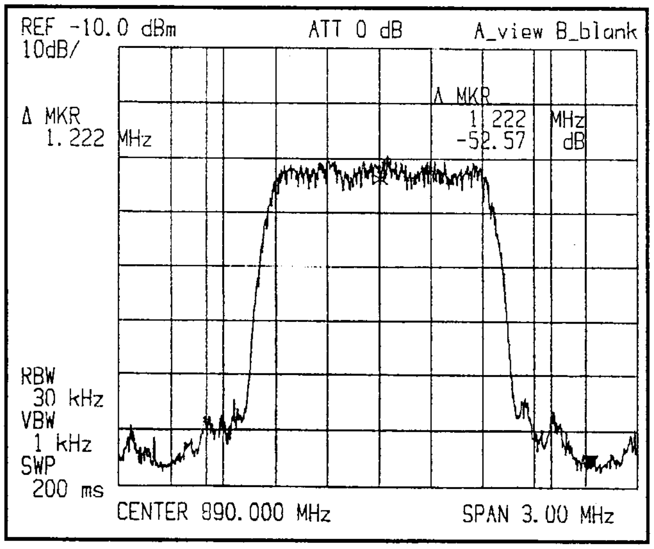
HARMONIC MEASUREMENT

- The harmonic level is determined as for any signal — just display the fundamental and harmonic and measure using the markers
- The result is 50.32 dBc



SIGNAL-TO-NOISE RATIO MEASUREMENT

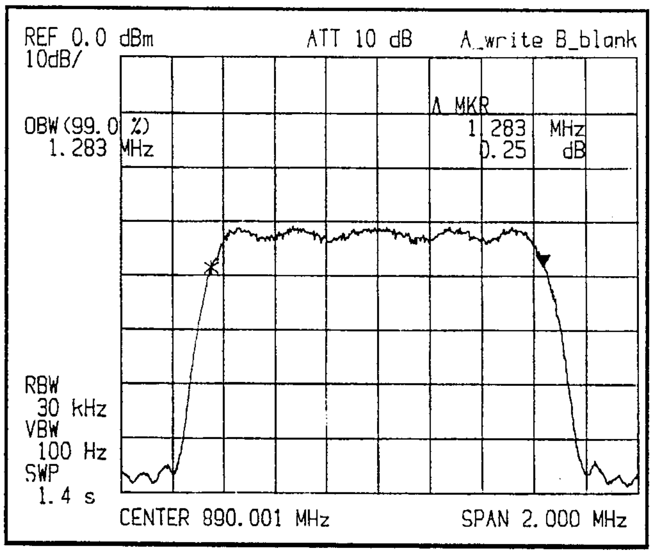
- Both the (CDMA) signal and the noise are random. Hence, no random noise correction factors need to be provided
- Simply set the markers to the frequencies of interest and measure the result — shown below as 52.6 dBc



USING THE SPECTRUM ANALYZER

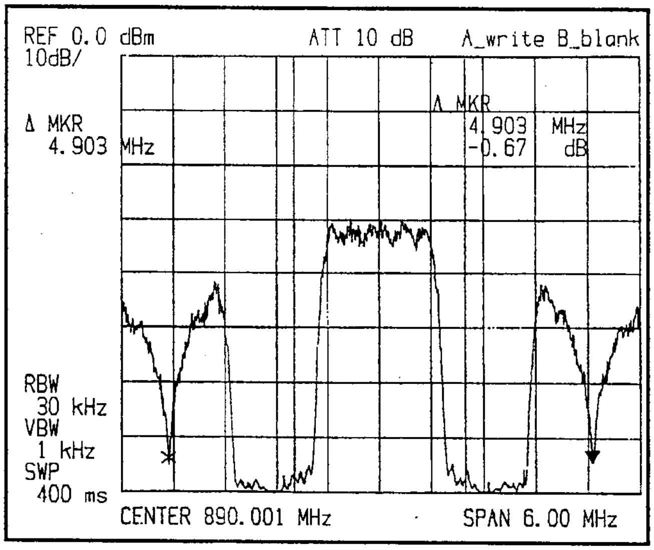
OCCUPIED TRANSMISSION BANDWIDTH

- The full 100% bandwidth is virtually impossible to determine accurately and repeatedly as very small band-edge signals may or may not be included; hence the practice to measure the 99% BW
- The spectrum analyzer menu can be set to measure any percent bandwidth automatically; there's no need to measure and compute from spectrum shape and power level
- The 99% BW shows at 1.283 MHz below (menu set for OWB 99%)



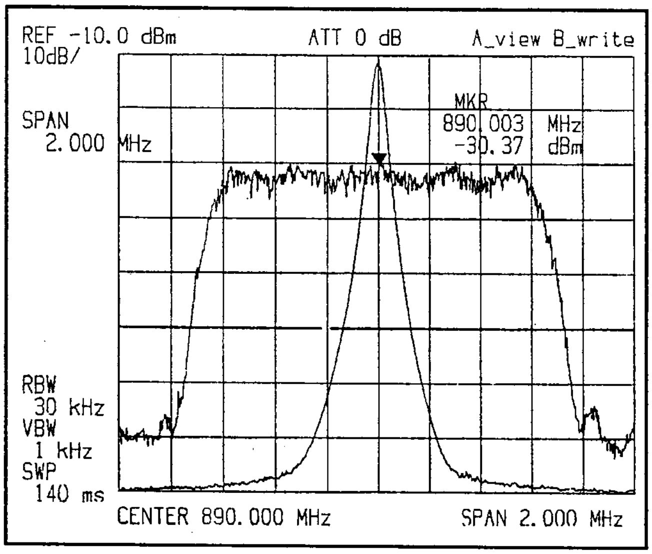
SIGNALLING RATE

- The signalling rate for this CDMA signal is known to be 2.45 MHz as that was the setting in the original simulation (see slide #4)
- This is easily measured across the null, drop-out points, of the expanded spectrum display shown below
- The spectrum nulls at 4.9 MHz difference are spaced at two times the signalling rate



COMPUTING TRANSMITTED POWER

- Formulas, such as 10Log(signal rate/BW) with respect to the unmodulated carrier, permit calculation of the total modulated transmitted power
- A signalling rate of 2.45 MHz and 34 kHz noise BW (same as 30 kHz res BW @ 3 dB), yields 10Log(72) = 18.6 dB
- This is in line with the modulated and unmodulated spectra shown below



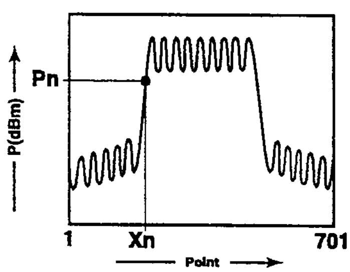
MEASURING TRANSMITTED POWER

- There are difficulties when computing transmitted power manually:
  - You need to know the formula for the signal involved
  - You need to be able to measure the factors needed for the formula, such as signalling rate and get to an unmodulated carrier
  - The computation shows all power, including that outside the specified bandwidth, which can be considerable (see slide #15)
  - The computation formula ignores spurious components
- The simplest and most accurate procedure is to measure the power on a digital storage bin-by-bin basis
- The channel power, noise power, average power, carrier power... all can be measured automatically by use of internal firmware

MEASURING TRANSMITTED POWER (cont'd)

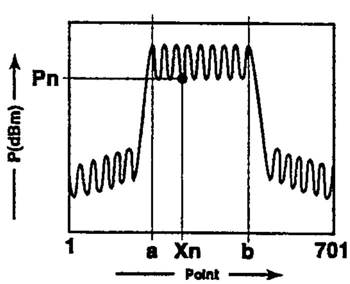
- **The measurement is made as a summation across all display digital storage memory points**
- **Some of the algorithm mathematics are shown below**

Average Power (P_{avg}) Measurement



(NORMAL)

$$P_{avg} = 10 \log \left[\frac{1}{701} \sum_{Xn=1}^{701} 10^{Pn/10} \right]$$



(With measuring Window)

$$P_{avg} = 10 \log \left[\frac{1}{b-a} \sum_{Xn=a}^{b} 10^{Pn/10} \right]$$

- **Function Set**
  - RBW<VBW (VBW = 10XRBW)

[SHIFT] [3] (UTIL) [AVG POWER ON / OFF]

[AVG TIMES] [1] [0] [Hz] (ENTER)

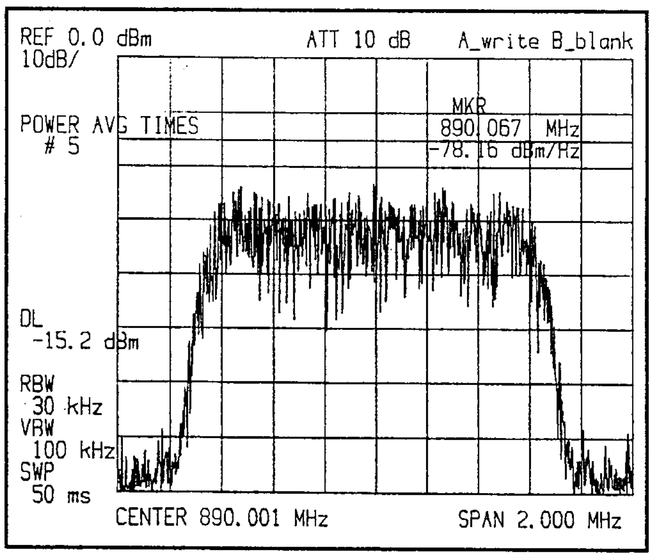
USING THE SPECTRUM ANALYZER

DIRECT MEASUREMENT OF TRANSMITTED POWER

- The spectrum analyzer does it all when you choose to do a direct measurement of transmitted power
- Set the display for the desired signal. This includes choice of frequency, span, and resolution BW
- Unlike the computed and manually corrected procedure, there must not be any signal smoothing or averaging
- The video filter BW should be wider than the resolution BW so that all signal perturbations are captured

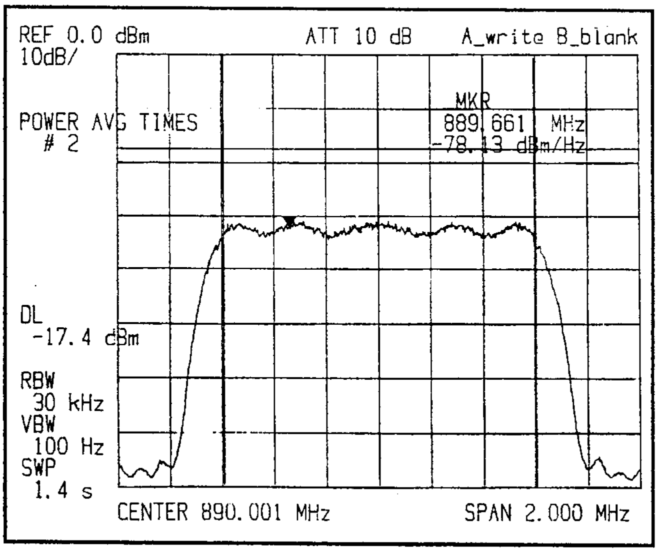
DIRECT MEASUREMENT OF TRANSMITTED POWER (cont'd)

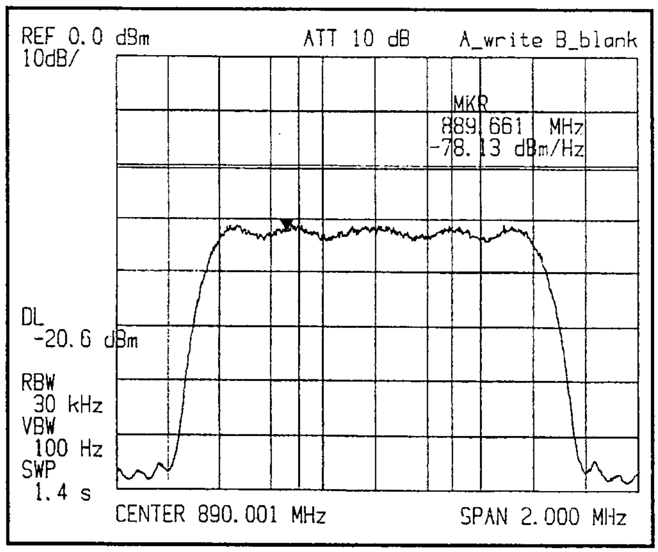
- Set the WINDOW width to include all of the spectrum to be measured and actuate the menu of choice
- The WINDOW was set to cover the whole screen width, showing a transmitted power level of –15.2 dBm and a power spectral density of –78.16 dBm/Hz



EFFECT OF WINDOW WIDTH

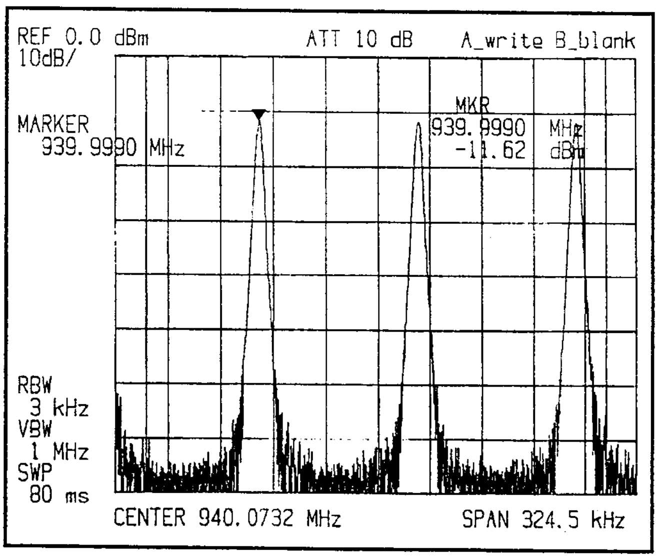
- **Changing the window width will change the measured power level. Changing the window width by 2:1 changes the measured result by 3 dB (–17.4 vs –20.6), but the power density remains unchanged at –78.13 dBm/Hz**

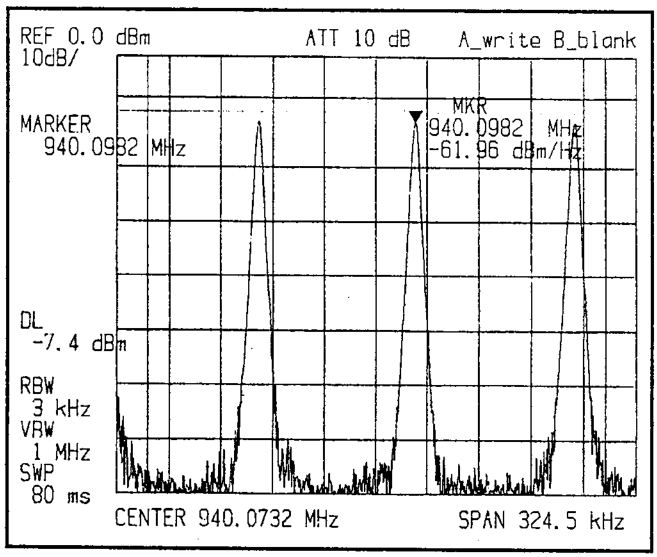




SINEWAVE POWER

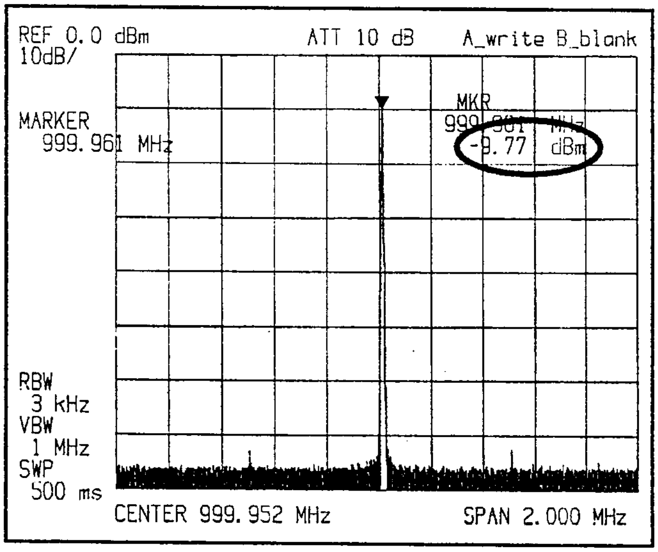
- Not only noise-like CDMA signals, but even ordinary sinewaves can have total power determined by the internal firmware
- One sinewave shows –11.62 dBm. Three sinewaves show –7.4 dBm. The computation for three equal amplitude sinewaves is –11.6 + 10Log3 = –6.8 dBm

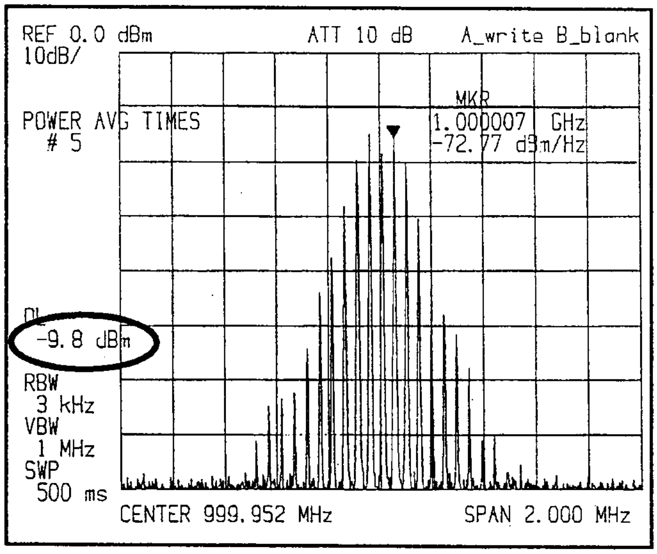




FM SIGNALS

- **Perfect FM will show no change in transmitted power no matter what the degree of modulation. Here the unmodulated carrier shows a level of –9.77 dBm, while the modulated signal is measured at, a virtually identical, level of –9.8 dBm**



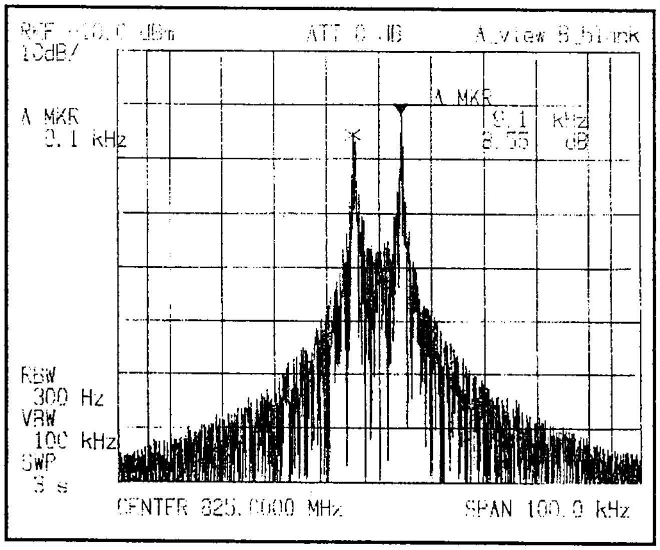


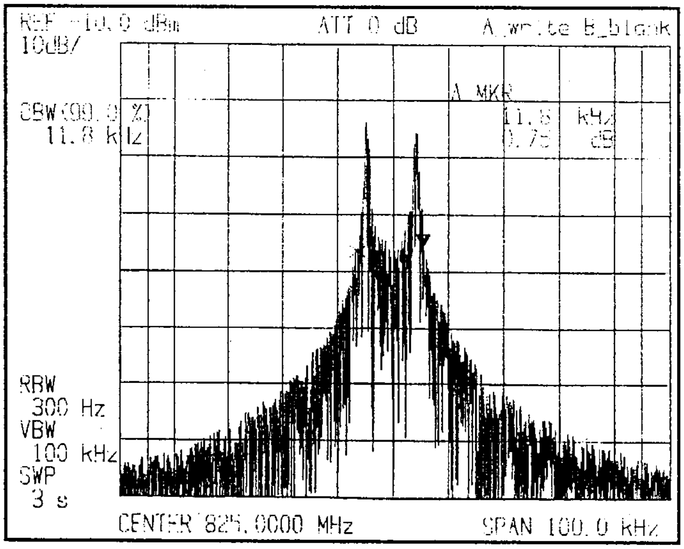
COMPLEX MODULATION MEASUREMENTS

USING THE SPECTRUM ANALYZER

Frequency Shift Keying — FSK

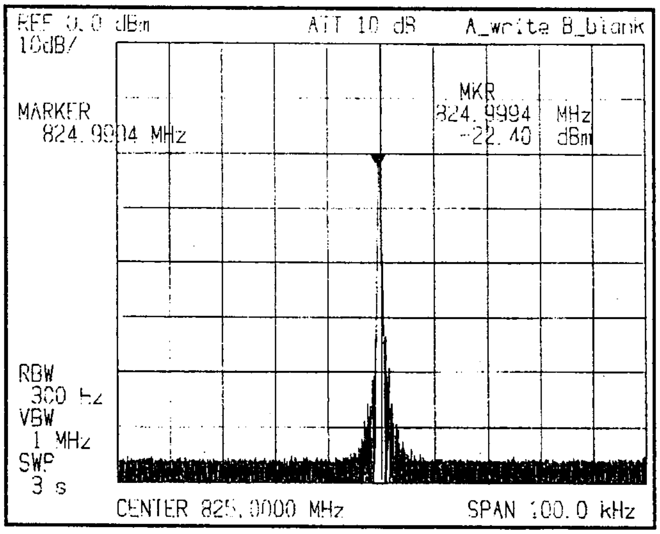
- **The space-to-mark frequency shift for a frequency shift keying signal is measured at 9.1 kHz — a perfect shift between two sinewaves would generate a 9.1 kHz wide spectrum. The actual spectrum has a 99% width of 11.8 kHz**

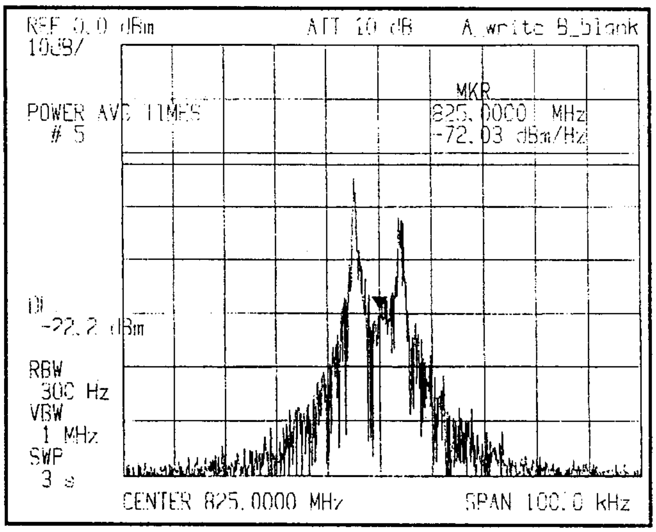




FSK TRANSMITTED POWER

- **The unmodulated carrier shows a level of –22.4 dBm, and the modulated spectrum is measured at an almost identical –22.2 dBm**
- **Total power of the FSK spectrum is determined using the PWR MEAS function**



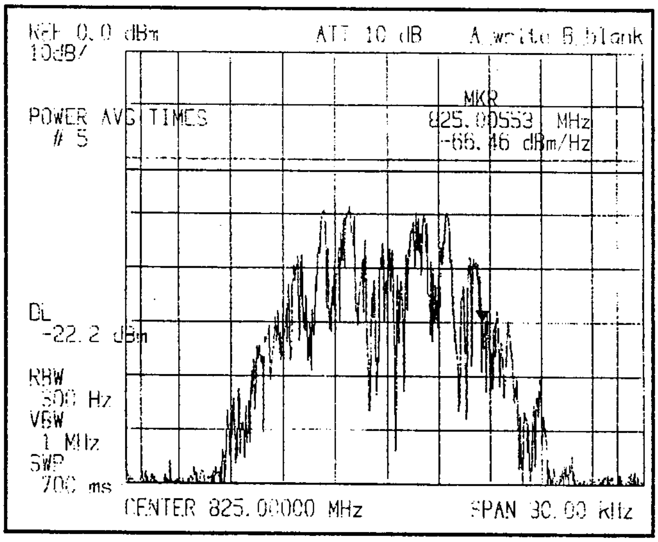


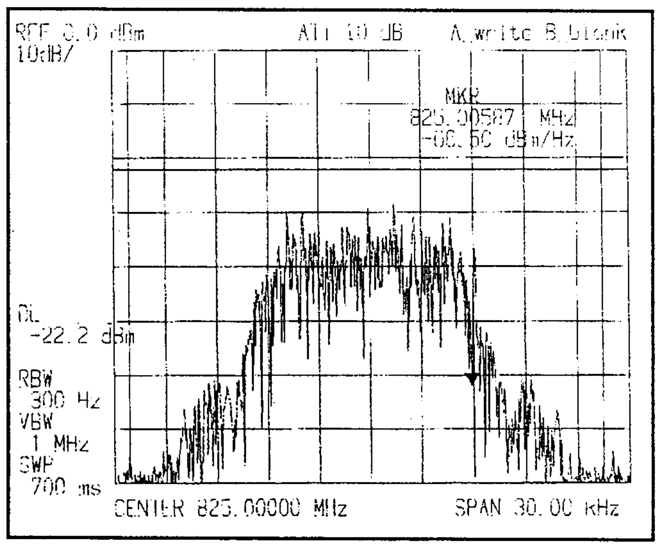
FAST FREQUENCY SHIFT KEYING — FFSK

AND

FOUR PHASE SHIFT KEYING — 4FSK

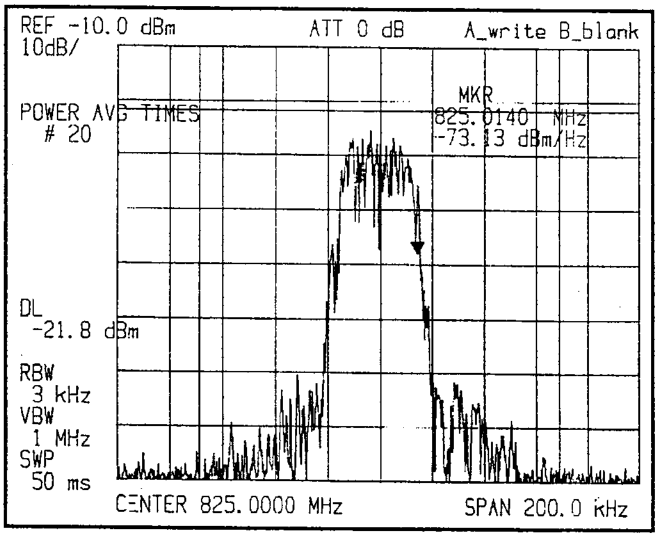
- **The spectra for fast FSK (left) and for 4FSK (right) show identical total transmitted power of –22.2 dBm and in excellent agreement with a –22.4 dBm carrier**

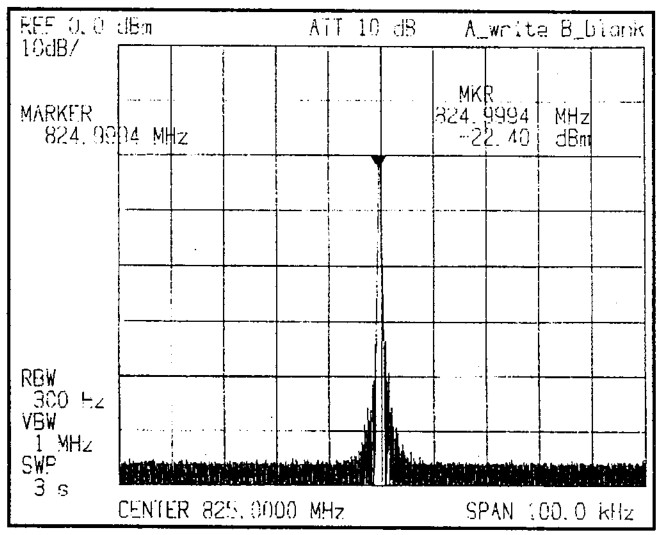




QUADRATURE PHASE SHIFT KEYING — QPSK

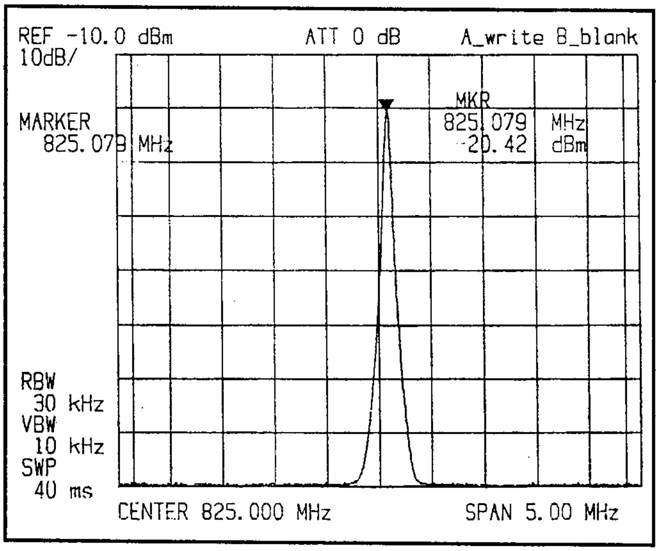
- **A quadrature phase shift keying spectrum shows a total power content of –21.8 dBm versus a 22.4 dBm unmodulated carrier**

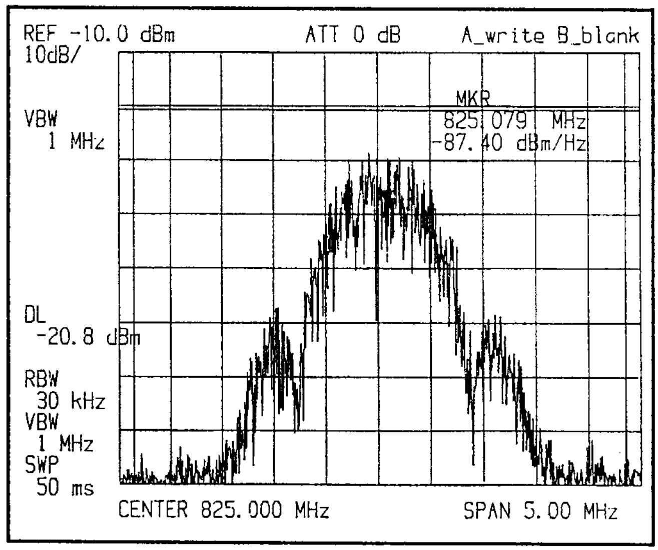




GAUSSIAN FREQUENCY SHIFT KEYING — GFSK

- **The carrier for a gaussian FSK signal at –20.42 dBm (left) and the modulated spectrum at –20.8 dBm (right) show essentially identical results**





CONCLUSION

- Powerful internal firmware permits some spectrum analyzers, such as the Advantest R3261C, to easily and accurately measure a variety of complex digital modulation features and total power content on a wide variety of signal types. Otherwise these measurements are difficult, time consuming and inaccurate — if they can be performed at all