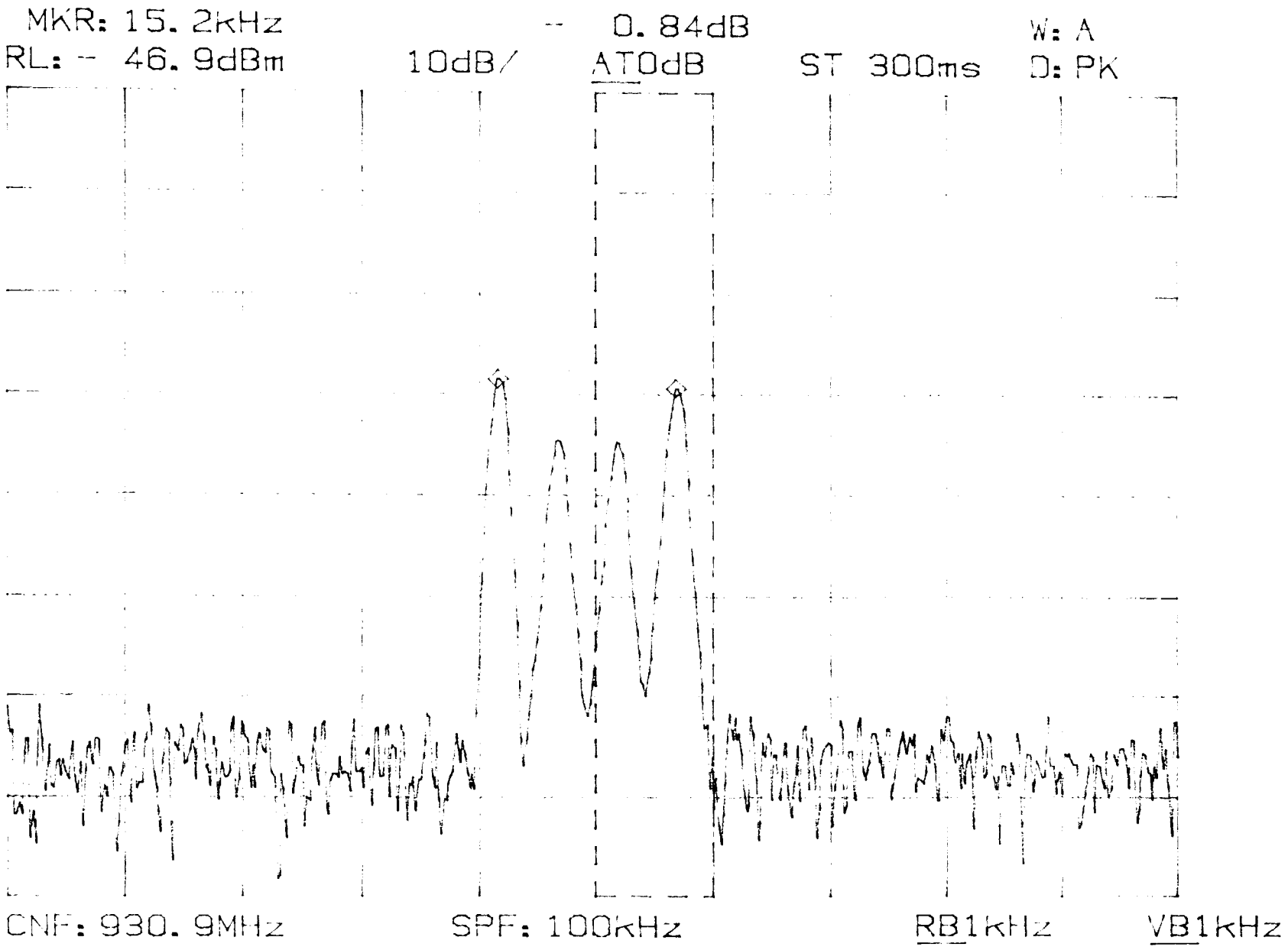
MKR: 15.2kHz
-- 0.84dB
W: A
RL: -- 46.9dBm
10dB/
AT0dB
ST 300ms
D: PK
CNF: 930.9MHz
SPF: 100kHz
RB1kHz
VB1kHz

Figure 19

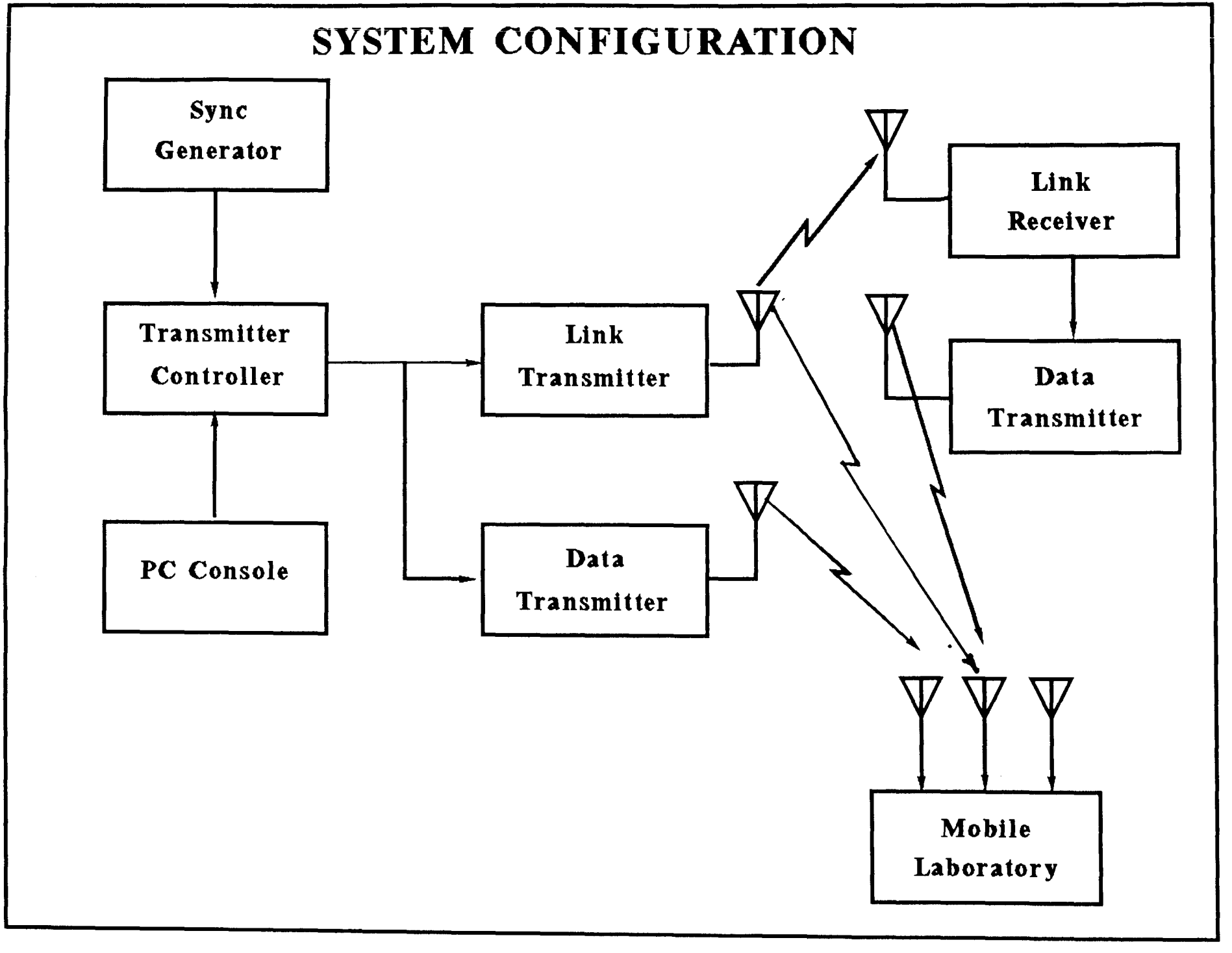
SYSTEM CONFIGURATION
Sync Generator
Transmitter Controller
PC Console
Link Transmitter
Data Transmitter
Link Receiver
Data Transmitter
Mobile Laboratory

Figure 20

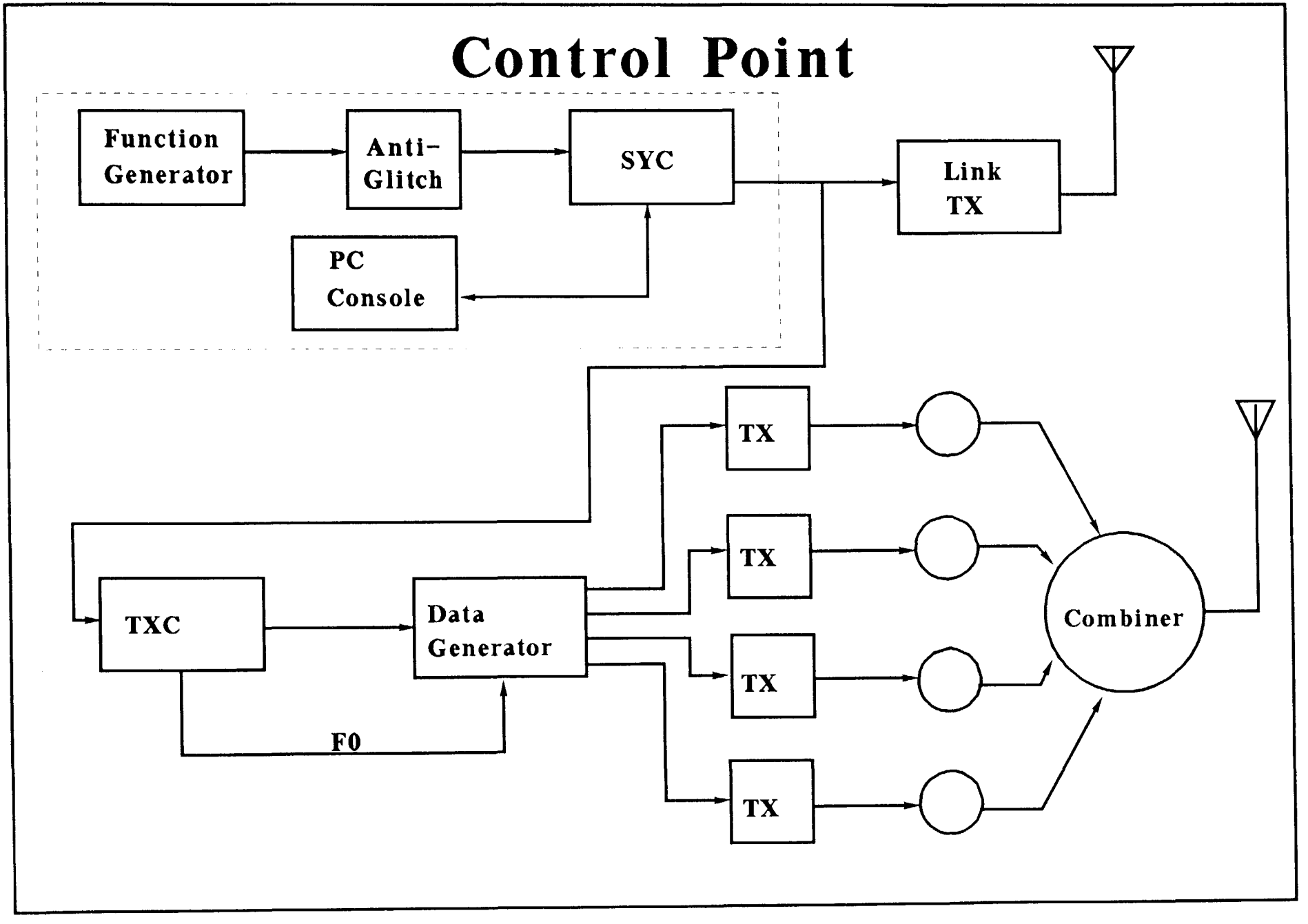
Control Point
Function Generator
Anti-Glitch
SYC
PC Console
Link TX
TX
TX
TX
TX
Combiner
TXC
Data Generator
F0

Figure 21

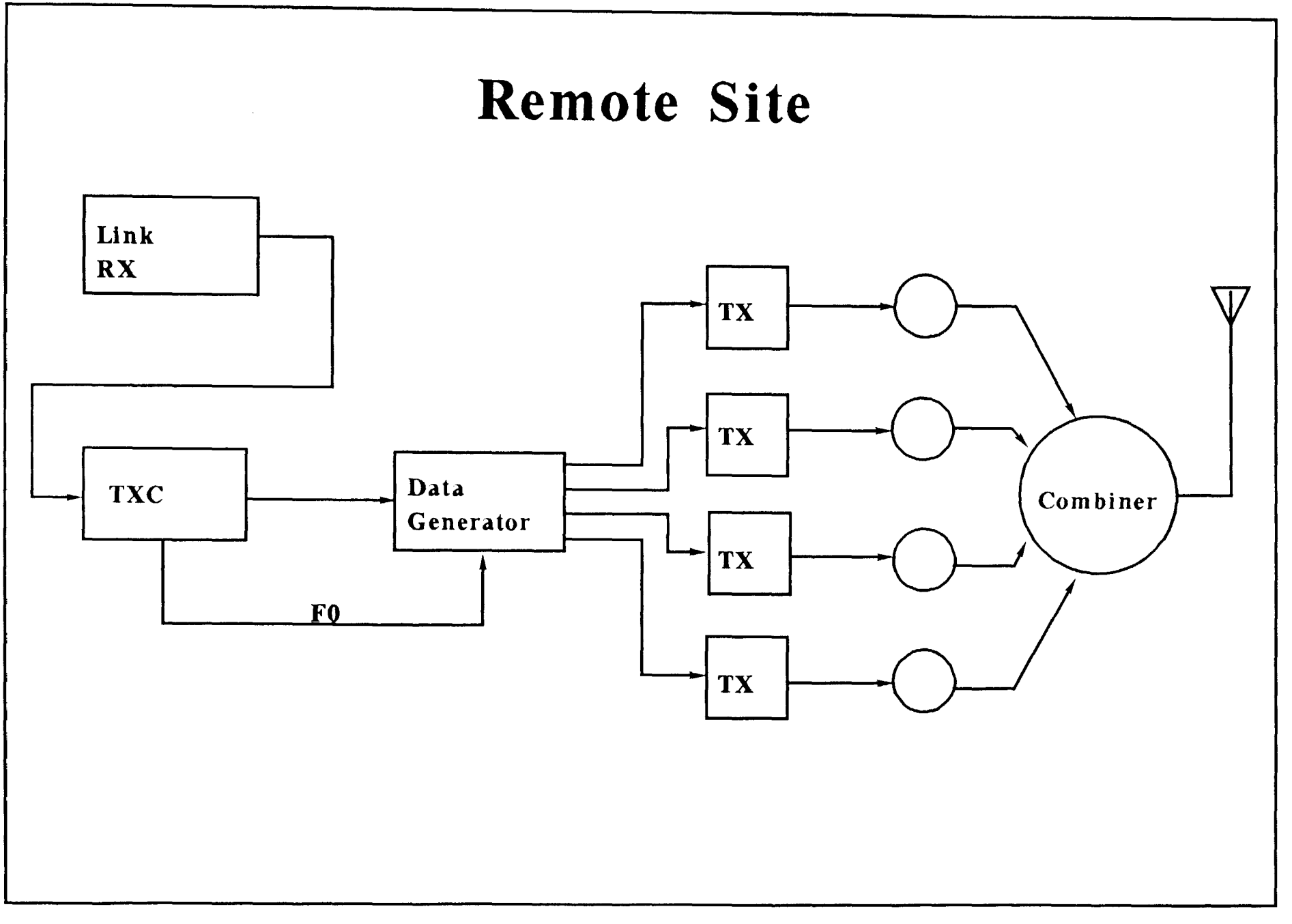
Remote Site
Link
RX
TXC
Data
Generator
F0
TX
TX
TX
TX
Combiner

Figure 22

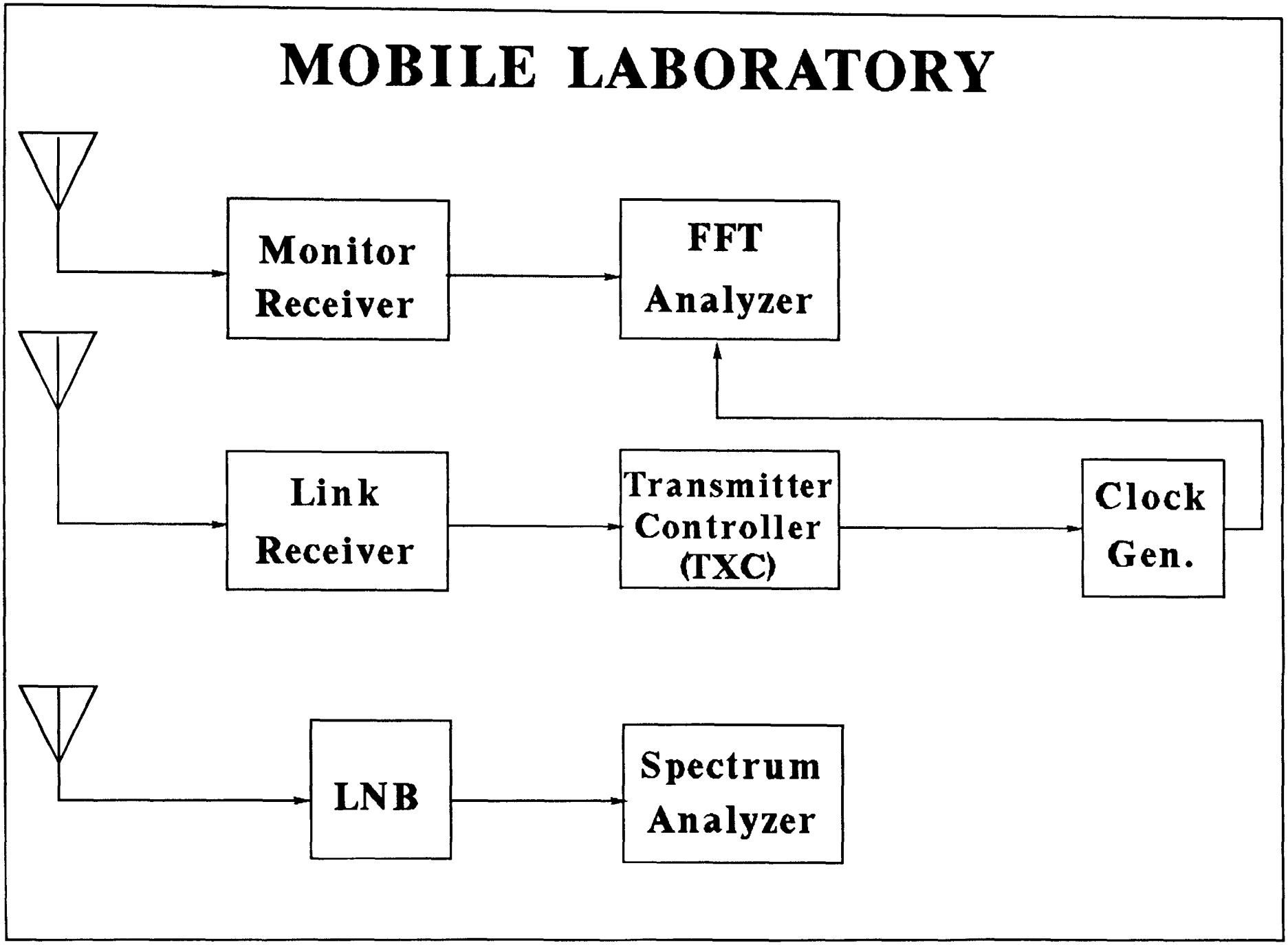
MOBILE LABORATORY
Monitor Receiver
FFT Analyzer
Link Receiver
Transmitter Controller (TXC)
Clock Gen.
LNB
Spectrum Analyzer

Figure 23

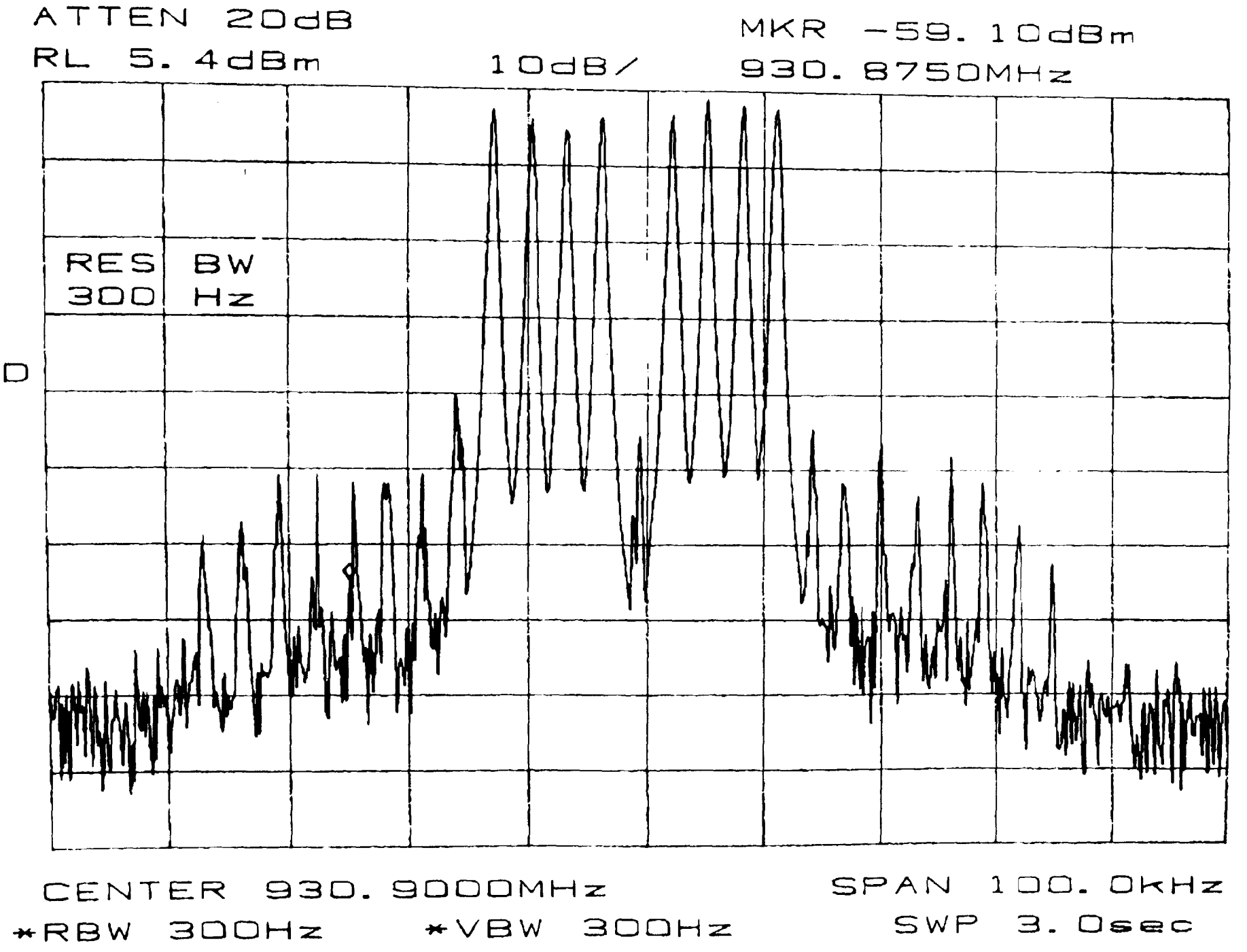
ATTEN 20dB
RL 5.4dBm
10dB/
MKR -59.10dBm
930.8750MHz
RES BW
300 Hz
D
CENTER 930.9000MHz
SPAN 100.0kHz
*RBW 300Hz
*VBW 300Hz
SWP 3.0sec

Figure 24

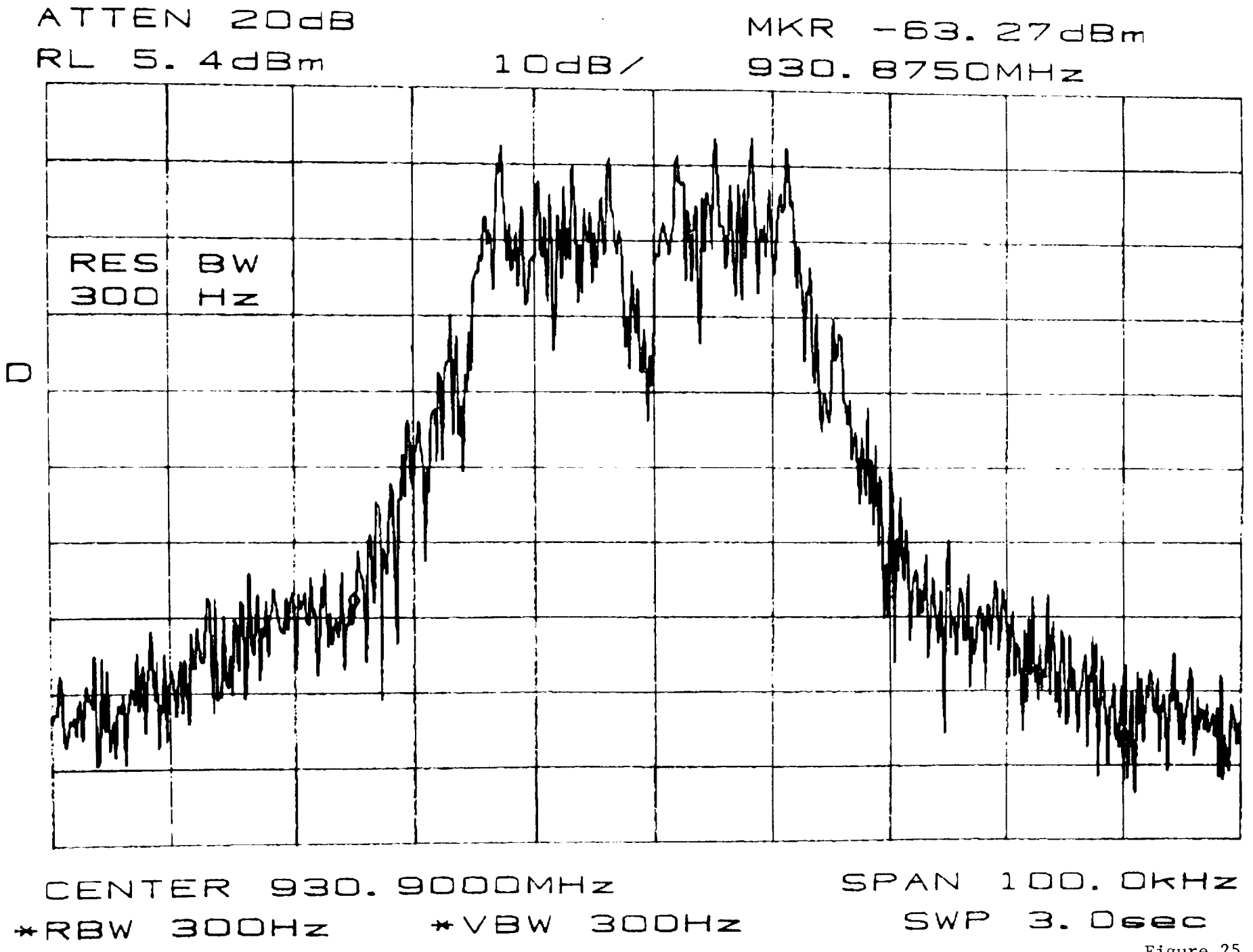
ATTEN 20dB
RL 5.4dBm
10dB/
MKR -63.27dBm
930.8750MHz
RES BW
300 Hz
D
CENTER 930.9000MHz
SPAN 100.0kHz
*RBW 300Hz
*VBW 300Hz
SWP 3.0sec

Figure 25

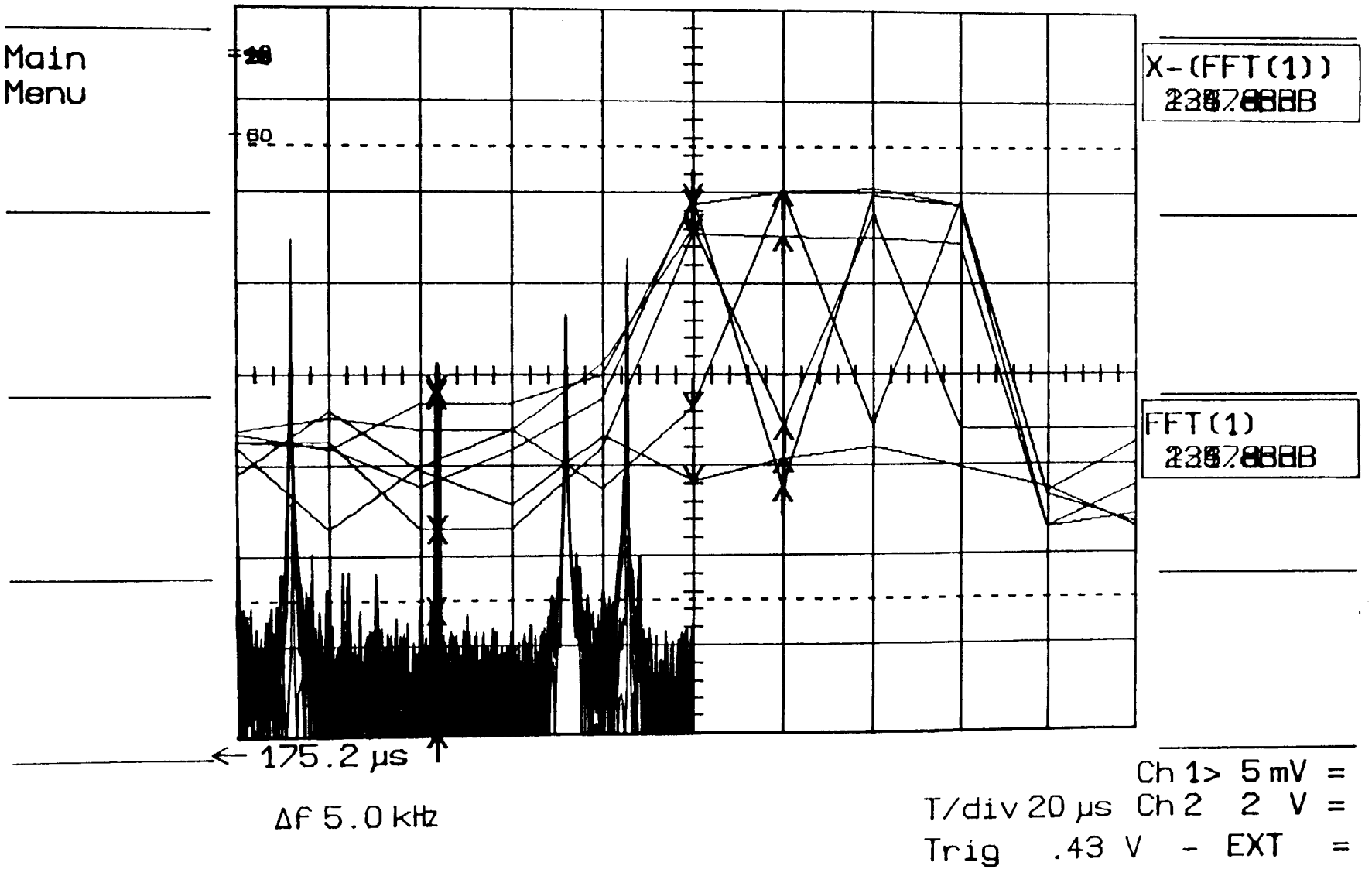
Main
Menu
60
X-(FFT(1))
FFT(1)
← 175.2 µs
Δf 5.0 kHz
Ch 1> 5 mV =
T/div 20 µs Ch 2 2 V =
Trig .43 V - EXT =

Figure 26

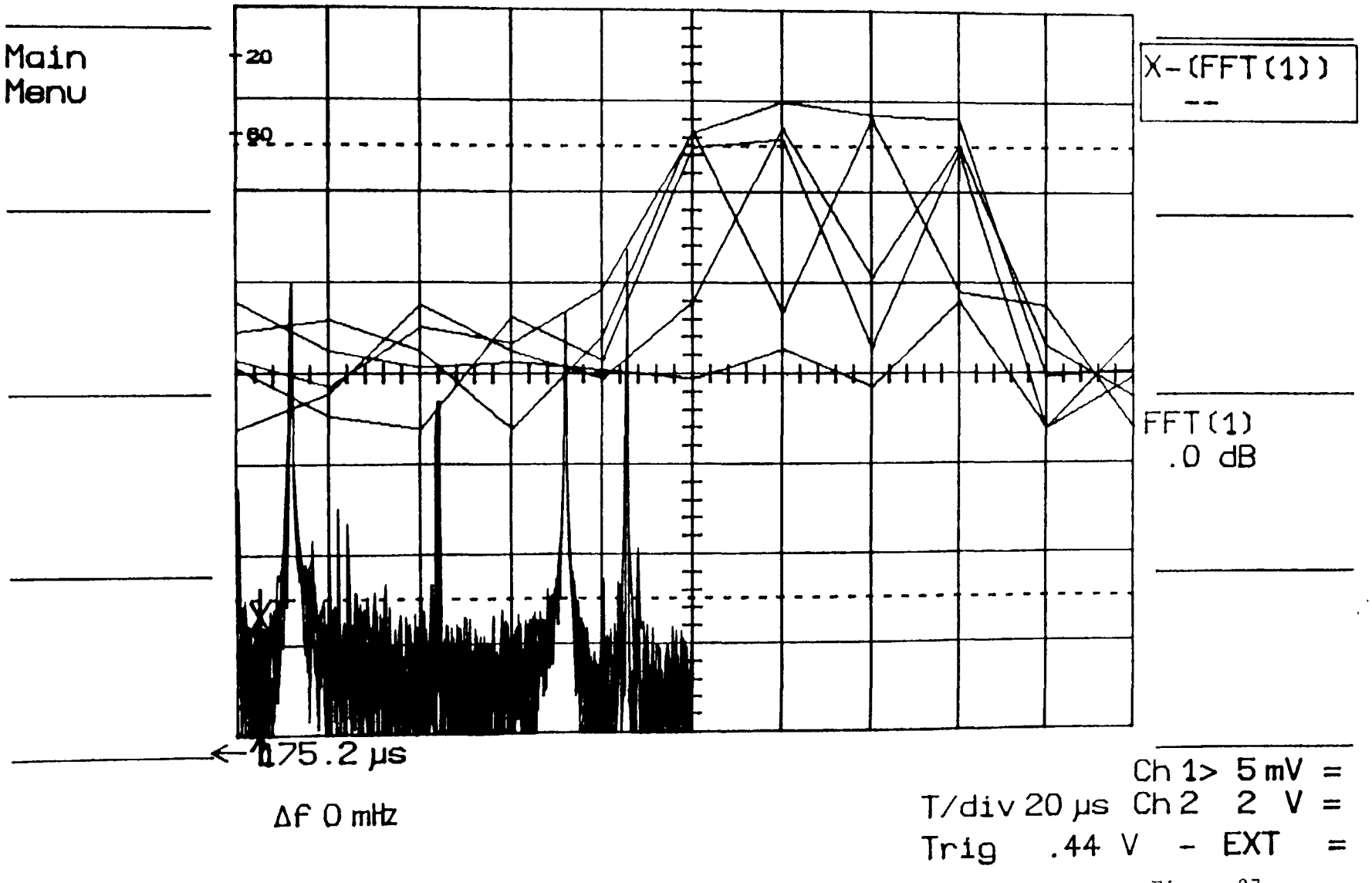
Main
Menu
20
80
X-(FFT(1))
--
FFT(1)
.0 dB
175.2 µs
Δf 0 mHz
Ch 1> 5 mV =
T/div 20 µs Ch 2 2 V =
Trig .44 V - EXT =

Figure 27

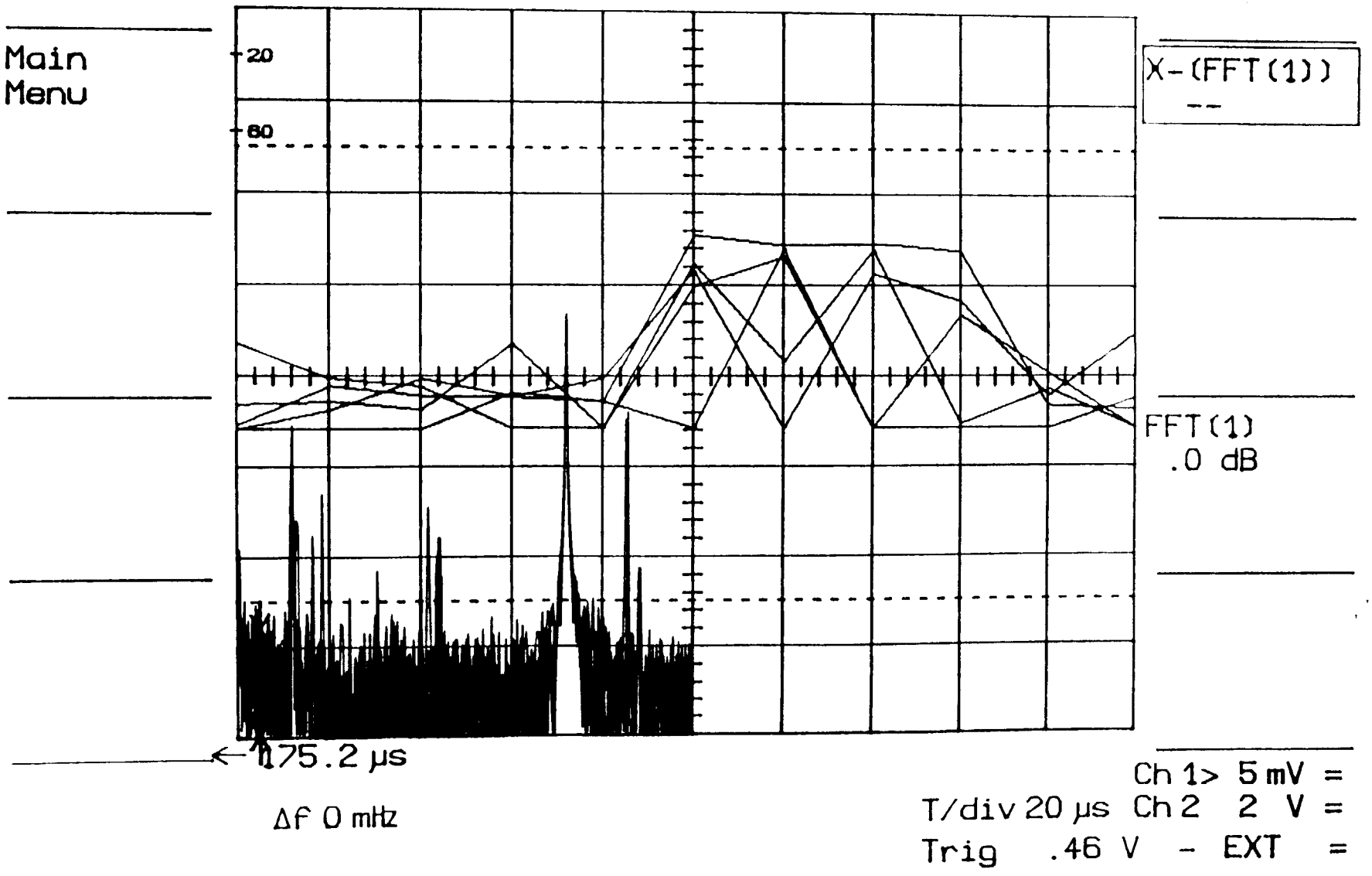
Main
Menu
20
60
X-(FFT(1))
--
FFT(1)
.0 dB
175.2 µs
Δf 0 mHz
Ch 1> 5 mV =
T/div 20 µs Ch 2 2 V =
Trig .46 V - EXT =

Figure 28

TAB A

APPENDIX A
MCM TRANSMITTER DEVELOPMENT

1.0 GENERAL SPECIFICATION

The transmitted tones must be capable of being individually turned on and off with at least a 30 dB on to off amplitude ratio. The rise and fall times of the tones must be less than 100 μsec and be shaped such that the AM sidebands caused by the on/off keying will fall within a 12.5 kHz displaced FCC sideband template for 25 kHz channel spacing at 900 MHz. Any intermodulation between tones must also be low enough to pass the above stated FCC template. Finally, the tones must be stable during the on/off keying to keep from adding FM sidebands to the transmitter output, thus spreading the spectrum.

2.0 DESIGN

The test MCM transmitters consist of 4 or 8 separate AM modulated amplifiers combined through a circulator combiner. An AM detector at the output of each amplifier is used to apply feedback around the modulated stages, providing over 30 dB of linear amplitude range. The squared keying/data pulses are filtered through a 10 pole, 4 kHz, Bessel Low Pass Filter. This signal is then applied to the transmitter modulator (see Fig. A1).

2.1 Synthesizer/VCO/Carrier Generator

The synthesizer is locked to a 10 MHz master oscillator with a stability of 1×10^{-9}. Plus and minus frequency offsets of up to 15 kHz are accomplished by adding or subtracting pulses from the 10 MHz reference going to the synthesizer. This method provides linear offset adjustment with very high stability. An on-frequency 930 MHz VCO with a noise level of less than -90 dBc in a 15 kHz BW on the adjacent channel is locked to this reference.

2.2 RF Amplifier

The pre-amp, driver, and power amplifier are class C amplifiers that provide enough gain to amplify the VCO output to about 45 Watts. Isolation between the synthesizer VCO and the modulated stages is high to prevent unwanted FM modulation of the VCO during the on/off keying. FM modulation was undetectable or less than 30 Hz at 900 MHz.

2.3 RF Combiner

The combiner consists of a 930 MHz circulator connected to the output of each amplifier. The outputs of the circulator are placed in parallel to sum the individual amplifiers and form the transmitter output. This method, although lossy, provides about -55 dB third order intermodulation to protect the adjacent channel. The transmitted energy of each tone is about 4 Watts.

2.4 AM Modulator

Each amplifier is modulated by varying the collector voltage of the driver. Because of the non-linearities in the RF amplifiers, feedback is applied around the modulated stages. An integrator in the feedback loop provides a large amount of DC feedback, decreasing at 6 dB/octave to prevent oscillation yet linearize the modulation. Over 30 dB of on/off linear amplitude range is accomplished.

2.5 Pulse Shaper

This circuit takes the data from the data generator and first squares it. It is then fed to a 10 pole, 4 kHz, Bessel low pass filter to shape the pulse for maximum rise time yet fit within the FCC sideband template. A rise time of less than 100 μsec is then applied to the AM modulation port and used to key each tone on and off as the data input dictates.

3.0 PERFORMANCE

In all cases the performance exceeded expectations. The spectrum of the transmitters was measured on an HP8567A Spectrum Analyzer with the resolution bandwidth set to 300 Hz. The first measurement, shown in Figure A2, was made with all of the carriers turned ON, spaced 3 kHz apart (with an additional space left in the center for possible insertion of a pilot carrier), and unmodulated. The main point of this measurement was to obtain the calibration of the display: the unmodulated carriers lie between -1 dB and -6 dB with the average level at approximately -4 dB. Since there are a total of eight carriers, the effective "unmodulated" carrier level is 9 dB above this average or +5 dB. With unmodulated

carriers, the sidebands do show evidence of discrete intermodulation products but they are all below the -50 dB level -- 55 dB below the "unmodulated" carrier level. When the carriers are amplitude modulated with a pseudo-random data stream the discrete sidelobes disappear, as shown in Figure A3. The envelope of the emissions are at -65 dB (-70 dB with respect to the "unmodulated" level) at the edge of the assigned channel ($\pm$25 kHz from the center frequency). Considering that these levels were achieved using only slightly modified off-the-shelf transmitters, with no attempt at optimization for this usage, the results are gratifying. There can be no doubt of the feasibility of successfully building transmitters of this general class to support MCM transmissions.

4.0 SUMMARY

Four or 8 units form the transmitter which provides the required modulation of the tines at data rates of up to 4800 baud. All sidebands caused by intermodulation or data keying fall within the 12.5 kHz shifted FCC sideband template for 25 kHz channel spacing at 930 MHz.

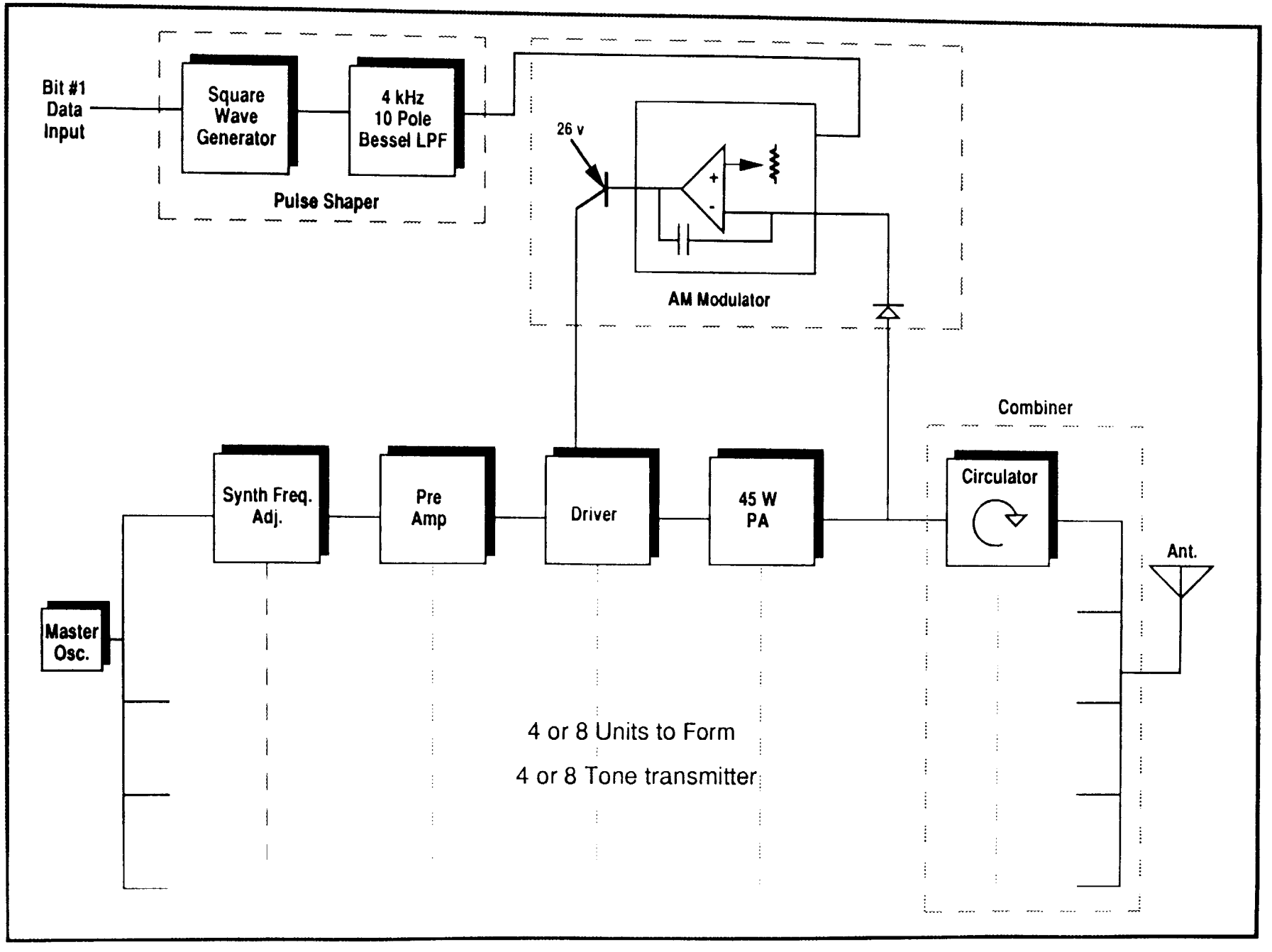
Bit #1
Data
Input
Square
Wave
Generator
4 kHz
10 Pole
Bessel LPF
Pulse Shaper
26 v
+
-
AM Modulator
Combiner
Synth Freq.
Adj.
Pre
Amp
Driver
45 W
PA
Circulator
Ant.
Master
Osc.
4 or 8 Units to Form
4 or 8 Tone transmitter

Figure A1

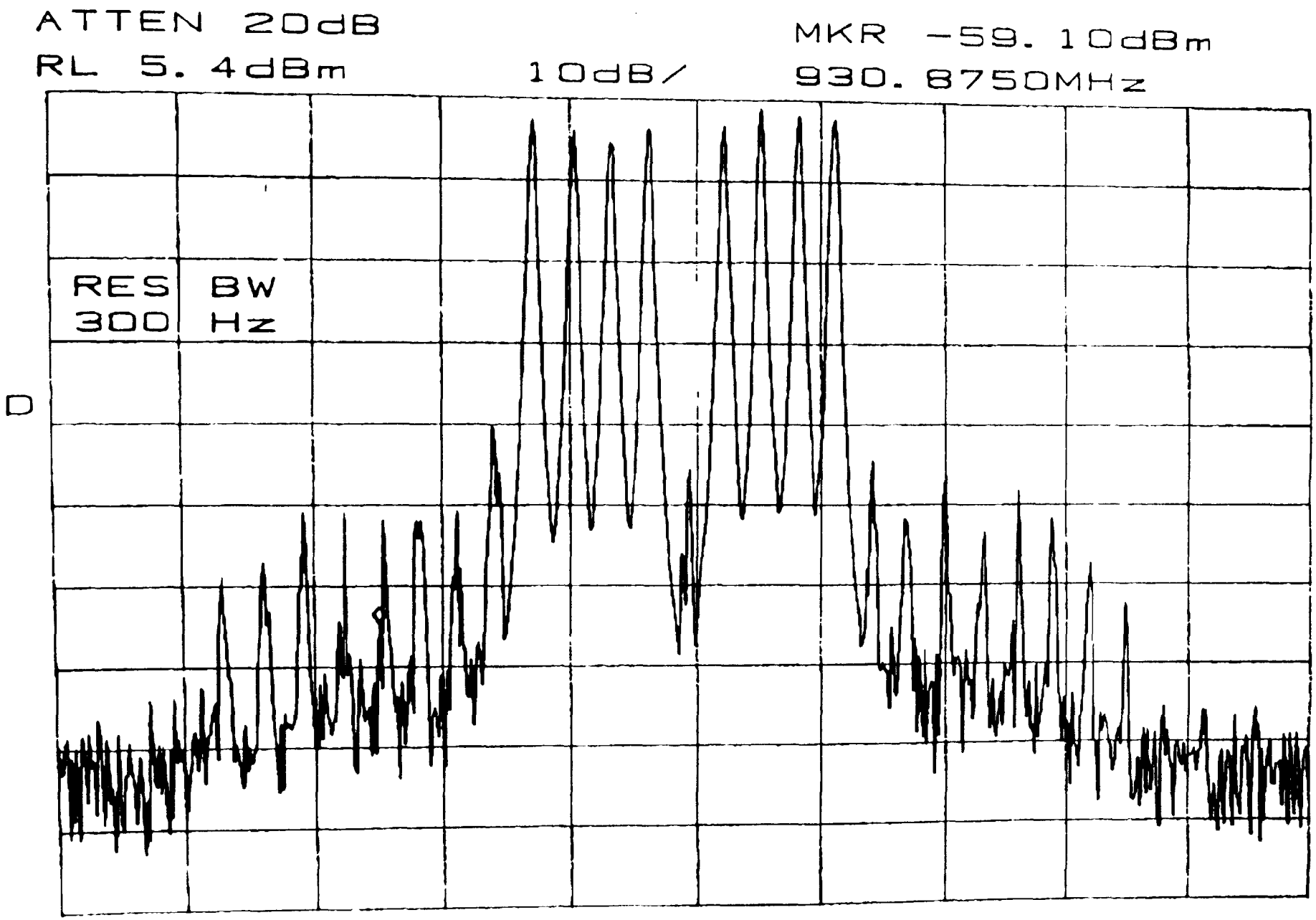
ATTEN 20dB
RL 5.4dBm
10dB/
MKR -59.10dBm
930.8750MHz
RES BW
300 Hz
D
CENTER 930.9000MHz
SPAN 100.0kHz
*RBW 300Hz
*VBW 300Hz
SWP 3.0sec

Figure A2

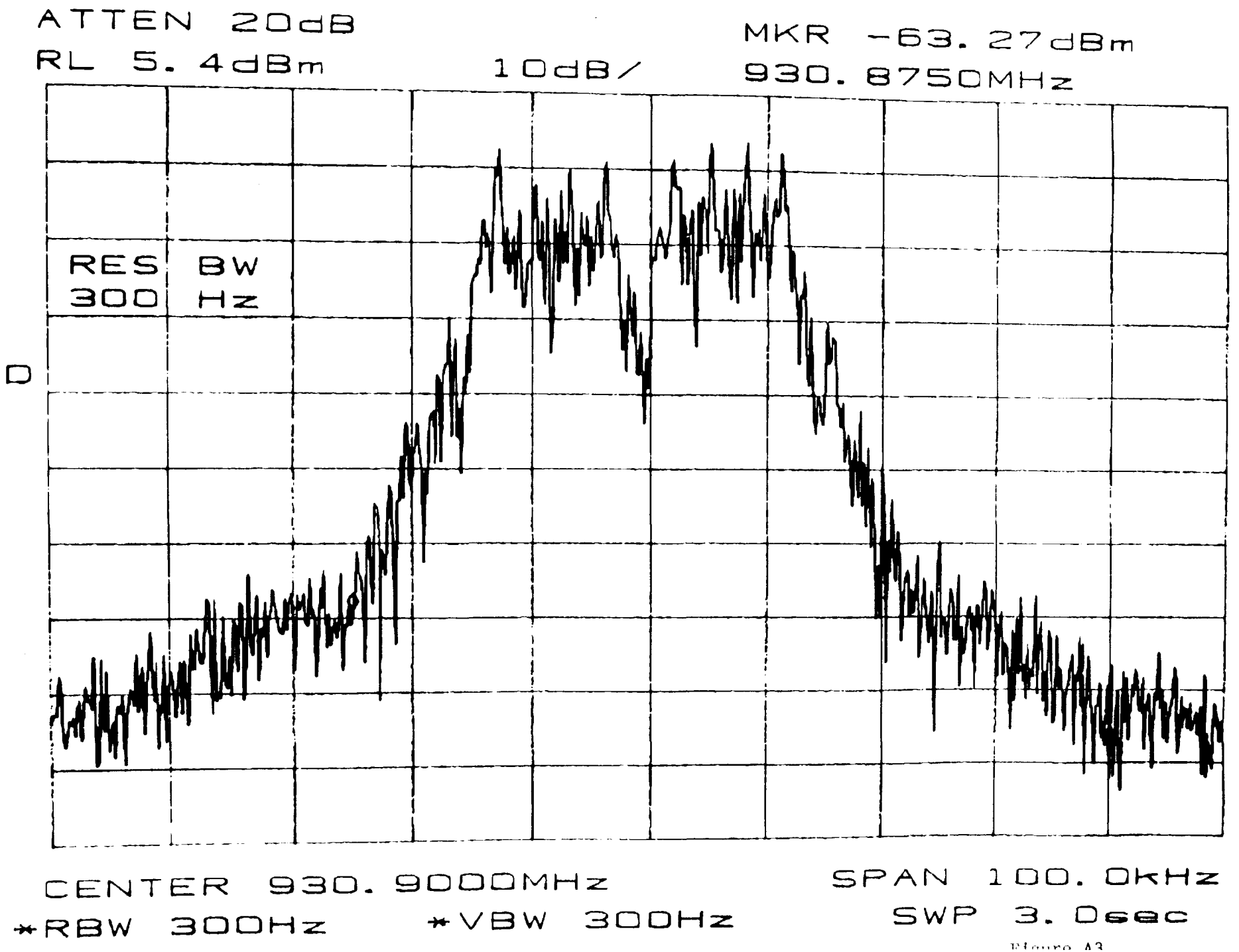
ATTEN 20dB
RL 5.4dBm
10dB/
MKR -63.27dBm
930.8750MHz
RES BW
300 Hz
D
CENTER 930.9000MHz
SPAN 100.0kHz
*RBW 300Hz
*VBW 300Hz
SWP 3.0sec

Figure A3

TAB B

APPENDIX B
FAST FOURIER TRANSFORM DETECTION

1.0 FFT PROCESSING OF MCM SIGNALS IN A LABORATORY ENVIRONMENT

In this stage of Mtel's verification of the NWN architecture, Mtel used a Fast Fourier Transform ("FFT") based receiver. The goal was rapid and low risk implementation of a proof of concept receiver -- the FFT capabilities of a high-end digital oscilloscope (the LeCroy 9400A) provided an off the shelf implementation of the required capability. The experimental setup is shown in Figure B1. The design of the transmitter is described in Appendix A. The attenuator provided sufficient loss to avoid overloading the receiver (approximately 70 dB for most test runs).

The receiver was a Glenayre RL900 dual conversion receiver. Because the second intermediate frequency of the receiver is normally at 10.7 MHz, the first IF is mixed with the signal from an external HP 8656A signal generator acting as the second local oscillator to bring the second IF down to a desired frequency band for processing by the FFT firmware in the LeCroy 9400A digital oscilloscope.

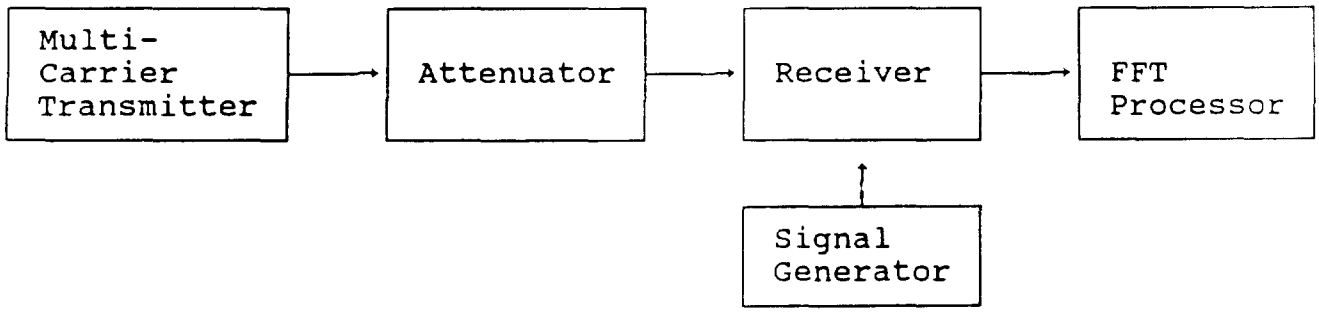

Fig. B1. Experimental Setup for the FFT Based Receiver

In this manner, all FFT processing was governed by the features built in the LeCroy 9400A firmware. Unfortunately, one of the inherent limitations in the LeCroy 9400A is the size of the FFT window, which could only be switched in steps of 1, 2, or 5. Since the window size has to be equal to $1/\Delta f$, where Δf is the frequency resolution of the FFT spectrum, Δf could also only be changed in steps of 1, 2, or 5. In other words, the frequency resolution could be 2 kHz or 5 kHz, but not 3 kHz, as Mtel originally intended. For these tests, Mtel chose to space the signaling tones at 2 kHz. In order to retain "orthogonality," 2 kHz spacing dictated decreasing the baud rate to 2 kbaud.

Figure B2 shows the spectrum of an MCM signal containing 8 tones,[7] as plotted by the HP 8567A spectrum analyzer. The setup parameters are listed on the plot. The center frequency is left unoccupied, reserved for a future pilot tone for AGC and/or decision threshold determination.[8] The center frequency is chosen to be nominally f_c = 930.9 MHz. The tones are thus at $f_c \pm 2$ kHz, $f_c \pm 4$ kHz, $f \pm 6$ kHz and $f_c \pm 8$ kHz. Figure B2 also shows that the intermodulation products are more than 40 dB below the level of any component carrier.[9] At the edge of the band the power is approximately 70 dB below the total unmodulated carrier power level.

---

[7] A number of laboratory tests of the 8 tone format were made in order to identify spectral occupancy and intermodulation problems. The remainder of the laboratory tests, and all of the field tests used a 4 tone format, which allowed deploying two composite (4 tone) transmitters. It was found that the 4 tone and 8 tone results were completely interchangeable -- parameters other than the number of tones (*e.g.*, the spacing of the tones, the accuracy of the spacing and the accuracy of matching the amplitudes of the tones) dominated the results. Therefore, in the following discussions the 4 tone and 8 tone tests are intermingled in order to illustrate specific points.

[8] The usefulness of a single central pilot is a topic of ongoing study. Leaving space for a pilot carrier in these 8-tone tests was done to provide the worst case spectral occupancy condition.

[9] The "unmodulated" carrier power of 8 carriers is 9 dB above the level of any one of the component carriers.

Another inherent limitation in the LeCroy FFT firmware is the coupling of the number of points for FFT analysis with the span of frequencies analyzed and displayed. For 8 tone detection, Mtel would theoretically need only 16 point FFT calculation or 18 point calculation for a 9 tone system (pilot included). The LeCroy FFT firmware offers 50 to 25,000 points. Increasing the number of points the LeCroy samples does not add any information about the amplitude of the tones, but it does provide information about the possible intermodulation products in the vicinity of the signal spectrum, which can be helpful in evaluating overall system performance. The "expand" feature on the LeCroy 9400A digital oscilloscope enabled Mtel to focus on the frequency domain of particular interest and improve the reading of the results. Based on the above considerations, Mtel decided to perform the FFT calculation with N = 50 or N = 125 sample points throughout the experiment. The results presented show both the full spectrum obtained from the FFT (in the bottom of the plot) as well as the expanded portion containing the signaling tones (in the middle of the plot).

The FFT calculation is performed on uniform samples of the signal displayed on the screen of the oscilloscope, using a fast implementation of the DFT (Discrete Fourier Transform):

$$X_n = \frac{1}{N}\sum_{k=0}^{N-1} x_k W^{nk}$$

In this equation, x_k is a complex array whose real part is the actual set of samples, and whose imaginary part is 0; X_n is the resulting complex frequency domain waveform; $W = e^{-i2\pi/N}$;

and N is the number of points in x_k and X_n. Mtel opted for a rectangular window, which provides the best resolution in the frequency domain.

Mtel also elected to display the laboratory results on the linear scale,[10] as the magnitude (M_n) of the complex frequency samples:

$$M_n = \sqrt{Re_n^{\ 2} + Im_n^{\ 2}}$$

In this calculation, Re_n and Im_n are the real and imaginary parts of the frequency domain signal.

The data pulses are shaped in the transmitter in order to reduce the signal spectrum, as described earlier. The shape obtained for a 2 kbaud rate is presented on the upper trace in Fig. B3. The lower trace shows the signal obtained from an AM receiver when only one tone is continuously keyed with the other tones kept low. The plot shows a substantial amount of distortion of the pulse shape due to incomplete extinction of the other seven tones during their lows. This noise source also appears in results discussed later.

In Figure B4, the middle trace shows a typical signal obtained when one transmitter is keyed on and off, while all others are off. This signal is obtained after the second mixing in the receiver (Fig. B1). The bottom trace shows the spectrum of the signal in the middle obtained by FFT analysis in 50 points. It shows a prominent peak at the signal frequency, a couple of small ripples in the vicinity (due to incompletely extinguished other tones), and a

[10] The field tests, with their greater variability, were displayed using logarithmic scaling.

flat spectrum in the rest of the 62.5 kHz band. The frequency separation between markers on this picture is given in the bottom left portion of the picture as Δf 50.0 kHz.

The time interval in the window actually contains two baud intervals. The synchronization is obtained directly from the clock used for the random data generator. This clock is displayed at the top trace. It was necessary to adjust the delay of the trigger in order to match the baud interval of the signal delayed through the transmitter and receiver with the FFT window.

The next two pictures (Figs. B5 and B6) show the effects of bit patterns 11 and 00 respectively in the same window. The change in the detected amplitude of the tone is as expected.

Figure B7, in the middle, shows the time domain trace of a single baud interval when four tones are on and four off and with second mixing tuned to place all tones between 32 kHz and 48 kHz. The number of samples in the FFT window was N = 125. The bottom trace shows the 0 kHz to 125 kHz range of the signal spectrum, while the upper trace shows the range between 30 KHz and 50 kHz. The upper trace clearly shows that the bit pattern during the particular baud interval was 01110001, as noted above the grid.

Figure B8 shows another example of the wave shape (middle trace) analyzed by a 125 point FFT, obtained spectrum on the full frequency scale (0 to 125 kHz) in the bottom part of the screen and blown up portion of the spectrum of interest (50 - 60 kHz) on the upper trace. This time only 4 tones are observed and the actual bit pattern was 1011, as noted above the grid. The second mixing was chosen to bring signals into the frequency range 50 -

60 kHz. The same bit pattern is analyzed using 250 point FFT and the results plotted in Figure B9. The only apparent result is the increased frequency range displayed.

The same bit pattern is analyzed once again using a 125 point FFT, but this time the second mixing is done using a 70.1 MHz local oscillator in order to position the signal spectrum between 2 MHz and 2.01 MHz. This change had no effect on the data relevant to detection of the tone pattern in the given symbol. The position of the signal spectrum prior to the FFT calculation can be chosen to simplify the sampling and A/D conversion process, while FFT process alone gives a wide range of options.

Figures B11 to B14 show shapes which are equivalent to standard eye diagrams, but this time the plot is in the frequency domain instead of the time domain. Each figure is obtained using a 125 point FFT. The figures contain two traces, with the bottom trace showing the full range of the spectrum (125 kHz) and the upper trace showing a blown up region of interest. All cases use 2 kHz tone separation. The first two figures show the frequency domain eye diagram (FDED) of two transmitters with four tones each (simulcast arrangement), while the last two diagrams show FDED of their combined signal (eight tones total).

The analysis of these diagrams leads to the following conclusions:

- The eye of each tone is open, which means that it is possible to distinguish 0 from 1 in the presence of the noise and interference existing in the experimental setup. The worst case FDED in that set of diagrams is the 3rd tone from the left on Fig. B14, where the relative eye opening (ratio between the smallest and the largest separation between 0 and 1 levels) is 41%.

- Noise (variation in pulse amplitude in state 0 or 1 of a tone) is larger at level 1 than at level 0.