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Inventors: Strutz et al.
Serial No.

PATENT APPLICATION
Navy Case No. 82,339

ALL OPTICAL IMAGE REJECT DOWN CONVERTER

BACKGROUND OF THE INVENTION

Field of the Invention

This invention is generally an optical down converter for the mapping of received radio frequencies into an arbitrary intermediate frequency range while precluding interference between the received signals and more specifically a device for improving image rejection to improve the harmonic spurs limiting system performance.

Description of the Related Prior Art

Currently there are primarily two types of image rejection systems that provide significant frequency translation. These are those which use a digital phase modulator to produce a serrodyne phase modulated waveform, and those which split a received signal into two parts and then recombine them in such a way as to eliminate the unwanted image and carrier frequencies. Optical image rejection mixers that utilize the serrodyne method of frequency translation apply a sawtooth waveform to phase modulate the optical signal, thereby causing the optical frequency to shift. The achievable image rejection is limited by the number of discrete bits that can be implemented by the digital phase modulator when approximating the sawtooth waveform. This limits the image rejection to approximately 25 dB.

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In the case of microwave image rejection mixers, the achievable image rejection is limited by the need for near perfect amplitude and phase control. As shown in **Figure 1**, a received radio frequency)(RF) signal **124** is first divided into two signals **106** and **108** in a in-phase power divider **122**, mixed in associated mixers **112** and **114** with a local oscillator input **102** (LO IN) and split into associated signals **106** and **108** that are shifted 90°in a first 3 dB 90° hybrid power divider **122**. The output of the mixers **112** and **114** are then recombined with a 90° phase shift between the two components in a second 3 dB 90° hybrid power divider **126** and output as an intermediate frequency band **134**. Exact amplitude and phase matching with broad band signals is nearly impossible with strictly microwave components since the frequency response of each component varies. A typical device, with a 3° phase error and a 0.25 dB amplitude imbalance upon recombination, is limited to about 36 dB of image and carrier rejection. Further details on serrodyne frequency shifting can be found in Johnsonet al., SERRODYNE OPTICAL FREQUENCY TRANSLATION WITH HIGH SIDEBAND SUPPRESSION, J. of Lightwave Tech., Vol. 6, No. 6, pg. 109, 1988.

A recently developed optical image rejection downconverter with > 60 dB of image rejection was recently developed and utilizes an electronic mixer to upconvert signals into the passband of a bandpass filter followed by optical downconversion of the filtered signals into a desired output band, as shown in **Figure 2**. **SEE**, U.S. Patent Application Serial No. (not yet assigned), by Ward et al., entitled IMAGE REJECTING MICROWAVE PHOTONIC DOWNCONVERTER, Navy Case No. 79,800, filed July 17, 2000. This device allows telecommunications systems to downconvert the lower sideband of densely multiplexed ultrawideband bandwidth channels into low frequency bands where conventional electronics can perform signal processing functions; has the image rejection (> 60 dB) to provide unambiguous signals for direction finding applications; and exhibits efficient image rejection that should permit multi-octave microwave frequency reception and compression. In addition, that invention is intrinsically remoteable, and due to the various optical and electrical components that they may be used to construct the invention contained in this application. However, the invention in Ward et al. utilizes a first local oscillator frequencies below the original frequency of a bandpass filter that may allow harmonics from the local oscillator to convert undesired input radio frequency (RF) frequencies into spurious signals presenting the output intermediate frequency band being applied to user electronics. These harmonics can be handled by the user electronics but additional signal processing would be required. It would be preferable to prevent such harmonics from reaching the user electronics.

SUMMARY OF THE INVENTION

The object of this invention is to is to provide an apparatus for the improvement of image rejection in image rejection mixing systems while removing harmonic spurs.

Another object of this invention is to provide a device having sufficiently large image rejection capability so as to allow precise determination of frequency for direction finding applications.

These and other objectives are accomplished by the all optical image reject down converter which maps received radio frequency (RF) into an arbitrary intermediate frequency (IF) range, while precluding interference between the received signals. The invention converts a received radio frequency signal into an arbitrary intermediate frequency for use by an electronic circuit in other devices. An example of the systems ability to convert a received 9 GHz signal into a 2 GHz intermediate frequency follows. Optical light originating from a laser is divided into two paths. Light in a first path is transferred into an optical sideband by a first optical modulator (MZM1) or phase modulator (LO1 = 25 GHz). At the same time , light in a second path is converted into 18 GHz sidebands by a second optical modulator (MZM2). The signal is amplified and additional sidebands are generated by a received 9 GHz signal. At this point, the optical spectrum in the second path consists of many optical wavelengths. Next, the light is passed through a narrow-band optical filter that is tunable which selects the 27 GHz sideband. Ideally, the optical spectrum of the second path consists only of light at the frequency equal to the original laser frequency plus the 27 GHz signal. Finally, the filtered sideband is recombined (heterodyned) with the 25 GHz signal of path one, resulting in downconversion to a 2 GHz signal. The use of a narrow-band optical filter allows the system to select a particular sideband for use in the heterodyne downconversion. As a result, image frequencies present in the optical link are filtered out and are rejected. The image rejection of the system is a function of filter extinction.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of an electronic image reject system present in the prior art.

Figure 2 shows a hybrid optical fiber/electronic image rejection downconverter of the prior art.

Figure 3a shows a schematic of light originating from a laser transferred into an optical sideband by a Mach-Zehnder modulator.

Figure 3b shows a light signal that has been amplified and with additional sidebands generated by a received 9 GHz signal.

Figure 3c shows a filtered sideband heterodyned with a 25 GHz signal resulting in downconversion to 2 GHz.

Figure 3d shows a radio frequency (RF) input at 5 GHz mixed with an 18 GHz sideband from a local oscillator to produce a 23 GHz sideband which is r ejected by the optical filter.

Figure 4 shows a block diagram of the all-optical image reject down converter set forth in the primary embodiment of this invention.

Figure 5 shows a block diagram of the optical image reject down converter with a polarization diverse output as set forth on a second primary embodiment allowing for the use of single-mode optical fibers after the modulators.

Figure 6 shows a plot of conversion loss versus image signal powers with a RF input power of + 20 dBm.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The general operational principles of this invention are depicted in **Figures 3a** through **3d** and the procedure whereby the system converts a received 9 GHz signal into a 2 GHz intermediate frequency for use by an electronic circuit in other devices. An optical light **12** originating from a laser is divided into two paths. Light in a first path is transferred into an optical sideband by a first optical modulator (MZM1) or phase modulator (LO1 = 25 GHz **14**, as shown in **Figure 3a**). At the same time, light in a second path is converted into 18 GHz sidebands **16** by a second optical modulator (MZM2). The signal is amplified and additional sidebands are generated by a received 9 GHz signal **18** (as shown in **Figure 3b**). At this point, the optical spectrum in the second path consists of many optical wavelength. Next, the light is passed through a narrow-band optical filter **22** that is tunable which selects the 27 GHz sideband **28** (as shown in **Figure 3b**). Ideally, the optical spectrum of the second path consists only of light at the frequency equal to the original laser frequency **12** plus the 27 GHz signal **24**. Finally, the filtered sideband is heterodyned with the 25 GHz signal **14** of path one, resulting in downconversion to a 2 GHz signal.

The use of a narrow-band optical filter **22** allows the system to select a particular sideband for use in the heterodyne downconversion. As a result, image frequencies **26** and **28** present at the radio frequency (RF) signal output of the filter **22** are rejected. For example, an RF input of 5 GHz signal **32** mixes with the 18 GHz (from a second local oscillator (LO2)) sideband **18** to produce a 23 GHz sideband **28**, as shown in **Figure 3d**. Without the filter **22** present, this would generate a duplicate 2 GHz signal **26**, as an image, at the output. Thus, the image rejection of the system is a function of filter **22** extinction.

In a first preferred embodiment, an optical image reject down converter **10**, as shown in **Figure 5**, light **32** at a frequency of approximately 1550 nm from a fiber coupled laser light source **34** (however, lasers of any wavelength may be utilized) is amplified in a first optical amplifier **33** and divided into two paths **36** and **38** by a first 3dB polarization maintaining (PM) optical coupler **42**. The light source **34** may be of any type that can be used to downconvert radio frequency (RF) frequencies through optical heteodyning and the optical amplifier **33** is optional and may be omitted. In a first path **44**, the light **32** is amplitude modulated by a first optical modulator (MZM1) **46** which is driven with a first local oscillator (LO1) **48** operating at a frequency of approximately 2-26 GHz. Virtually, frequency band may be chosen > 100 GHz so long as the proper combinations of LO1 **48** and LO2 **58** frequencies is used. The amplitude modulation causes light to be shifted from the fundamental beam **32** into the RF sidebands.

The second path **52** utilizes two cascaded optical modulators (MZM2) **54** and MZM3) **56**. MZM2 **54** modulates the light **32** at 18 GHz with a second local oscillator (LO2) **58** causing the generation of optical sidebands. The light **62** is then amplified in a second optical amplifier **64** before being modulated a second time by the third optical modulator **56** with an applied RF signal **66**. At this point, the path **52** with the cascaded optical modulators **54** and **56** contains wavelengths at the fundamental frequency (1550 nm) **32**, the fundamental ± 18 GHz, the fundamental ± RF input frequency **66**, and the fundamental ± 18 GHz ± RF input **66**. The light

68 is amplified in a third optical amplifier **72** and passed through an optical filter **74** that selects one of the optical sidebands. However, instead of a single optical filter **74**, multiple optical filters in each signal path **44** and **52** may be used. The two paths **44** and **52** are then recombined in a second 3dB polarization maintaining (PM) optical coupler **76**, the beat signal produced by heterodyning the light at the filtered signal **78** with the sideband produced by LO1 **48** is detected and an intermediate frequency (IF) output **82** is applied to an optical transmission line for appliction to user electronics (not shown) at a remote location.

The optical modulators, MZM1 **46**, MZM2 **54** and MZM3 **56**, are preferably Mach-Zehnder type optical modulators or phase modulators, however, it is well known to those skilled in the art that other types of optical modulators capable of generating optical sidebands may be utilized. The optical amplifiers, AMP1 **33**, AMP2 **64** and AMP3 **78**, are preferably Erbium doped fiber amplifiers (EDFA), however, it is recognized by those skilled in the art that other types on amplifiers may be utilized as long as they are capable of maintaining the polarization of light. If a high power laser source **34** is used, the first optical amplifier AMP1 **33** may not be required. All-optical amplifiers are optional and may be omitted depending on the performance required.

The RF input powers of LO1 **48** and LO2 **58** were fixed to 30 dBm, however, lower powers may be utilized. PM fiber is required for this system up to the second optical fiber coupler **76**, however, single mode optical fiber may be substituted for the PM fiber with the proper placement of polarization controllers, or with the use of polarization independent modulators.

In a second preferred embodiment, an optical image reject down converter **20**, having a polarization diverse scheme is possible at the system output, as shown in **Figure 5**, this would relax the requirement of a PM fiber. PM fiber would only be required up to the light modulators in each link or within the dashed box **92**. Also, a polarizing beam splitter **86** to direct the IF signal **82** having a differing phase relationships **84** and **88** to an optical transmission line for application to user electronics at a remote location.

In an experimental test to verify the functionality of the wideband image rejection system **10** as described above, the conversion loss (CL), and image rejection capability of the system were measured. **Figure 5** shows the power of the converted signals versus the RF input frequency. The converted signal power was 30-40 dB (CL=30-40 dB) below the + 20 dBm RF input power. The variation in the CL was found to be due in part to the throughput of the optical filter, which was set to a fixed value for each LO2 **58**. Lower conversion losses resulted from frequency shifts near to the center wavelength of the optical filter.

Next the image rejection properties of the system **10** were measured. The RF frequencies in the image band of each local oscillator, LO1 **48** and LO2 **58**, frequency combination were rejected. As shown in **Figure 5**, the converted image signals were 20-30 dB below that of the described signals. The image rejection performance of this system **10** is typical of the performance reported using other optical mixing techniques, and is a function of the optical filters **74** extinction.

The invention described herein is an all optical image rejection system that provides a unique and novel improvement to the efficiency of image-rejection frequency shifters and mixers and is an improvement over the hybrid RF/optical image rejection mixers in the prior art, since no electrical mixers are used and that optical phase modulators may be used. More than 20 dB of image rejection, dependent upon the efficiency of the optical bandpass filter utilized, has been shown. Ultrawideband microwave frequency bands may be mapped into narrow frequency bands to simplify processing and the large image rejection capability of this invention allows the precise determination of frequency for direction finding applications. Also this invention allows a method to shift frequency for radar applications.

Although the invention has been described in relation to an exemplary embodiment thereof, it will be understood by those skilled in the art that still other variations and modifications can be affected in the preferred embodiment without detracting from the scope of the invention as described in the claims.

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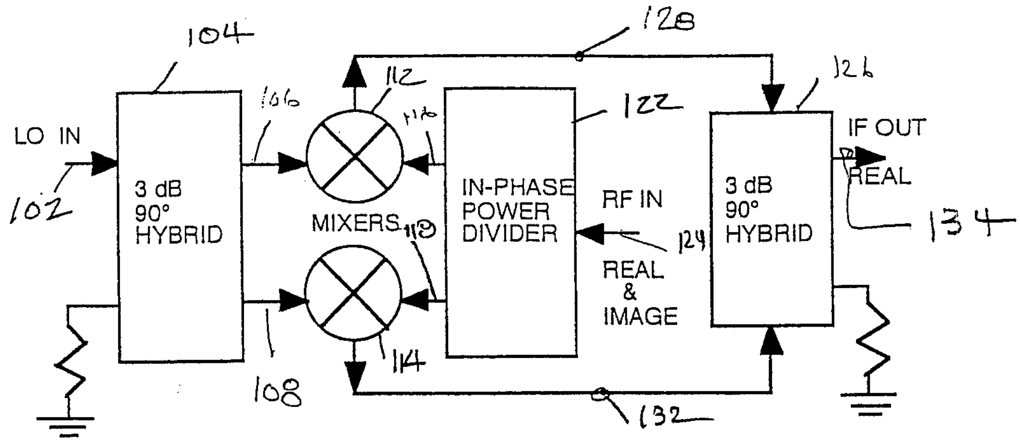
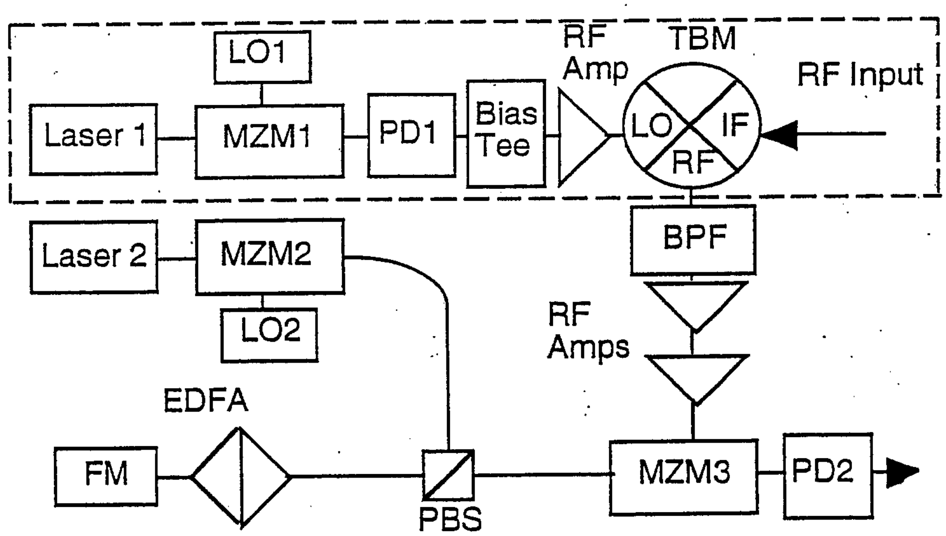
ABSTRACT OF THE INVENTION

The optical image reject down converter maps a received radio frequency (RF) into an arbitrary intermediate frequency range and precludes interference between the received signals. A received radio frequency signal is downconverted into an intermediate frequency band for use by an electronic circuit in other devices. Optical light is divided, in a first path light is transferred into an optical sideband by a first optical modulator or phase modulator. Light in a second path is converted into 18 GHz sidebands by a simarly. The signal is amplified and additional sidebands are generated by a received 9 GHz signal. The light is then passed through a tunable narrow-band optical filter which selects the 27 GHz sideband. The optical spectrum of the second path consists only of light at the frequency equal to the original laser frequency plus the 27 GHz signal. The filtered sideband is heterodyned with the 25 GHz signal of path one, resulting in downconversion to 2 GHZ Image frequencies which are present in the optical link are filtered and are rejected.



Prior Art

Figure 1



Prior Art

Figure 2

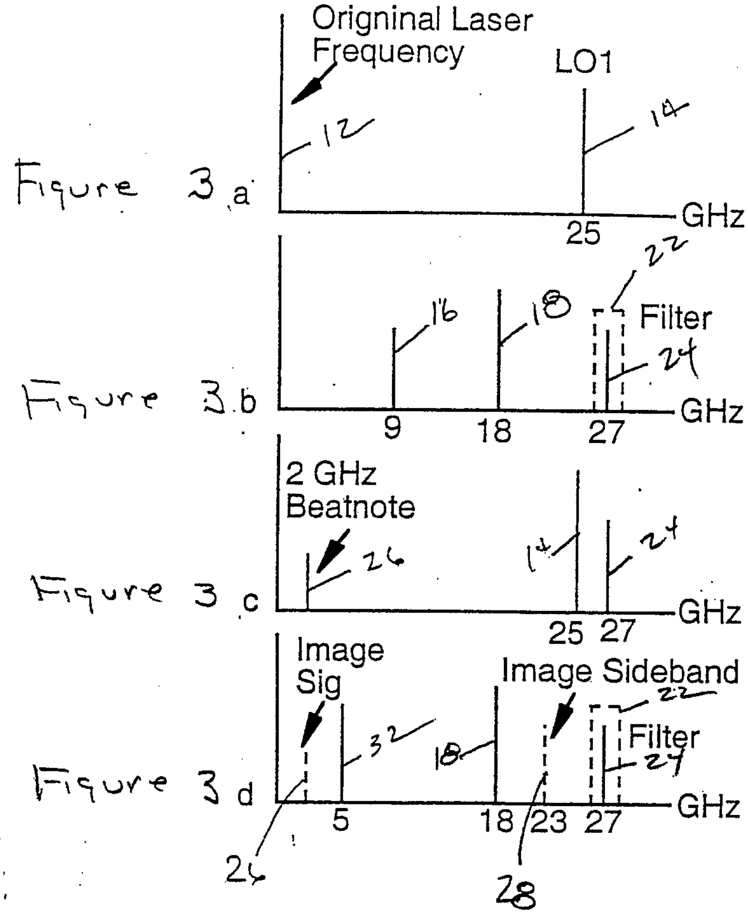


Figure 3a
Oriqinal Laser Frequency
LO1
12
14
25
GHz
Figure 3b
16
18
22
Filter
24
9
18
27
GHz
Figure 3c
2 GHz Beatnote
26
14
24
25 27
GHz
Figure 3d
Image Sig
Image Sideband
32
18
22
Filter
24
5
18
23
27
GHz
26
28

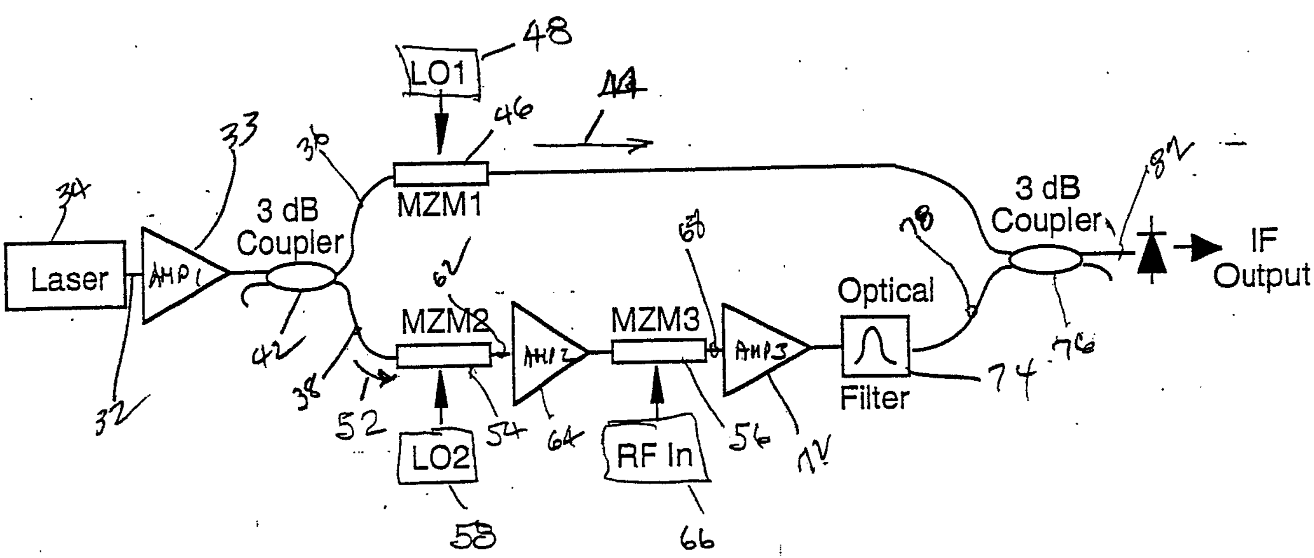

48
LO1
46
44
33
34
36
3 dB Coupler
MZM1
82
3 dB Coupler
IF Output
Laser
AMP1
68
78
62
MZM2
MZM3
Optical
AMP2
AMP3
Filter
74
76
42
38
52
54
64
56
72
32
LO2
RF In
58
66

Figure 4

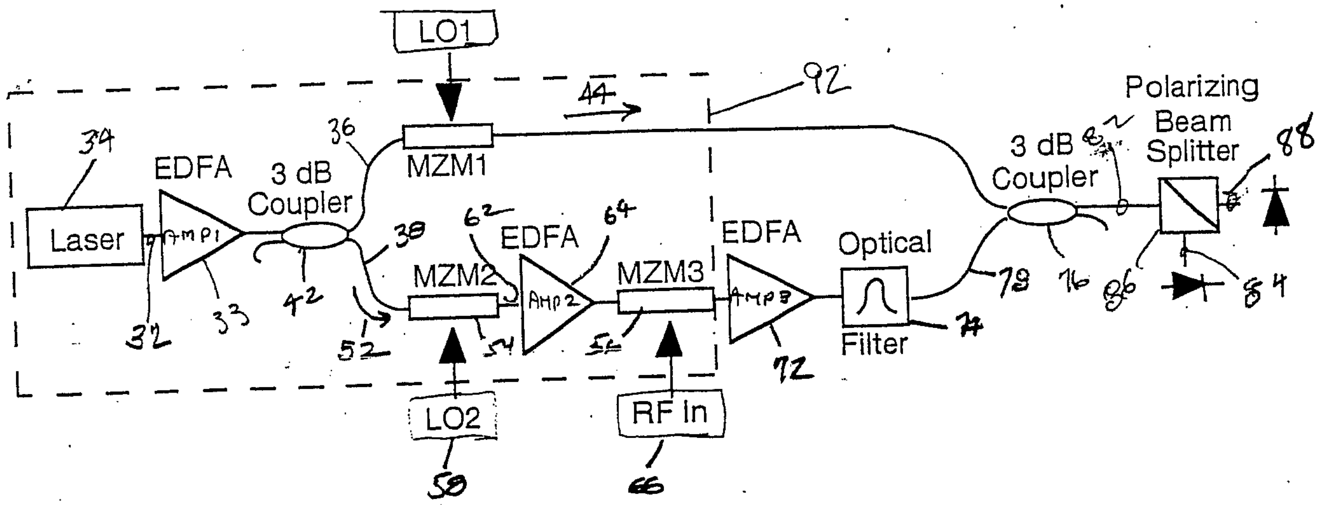


Figure 5

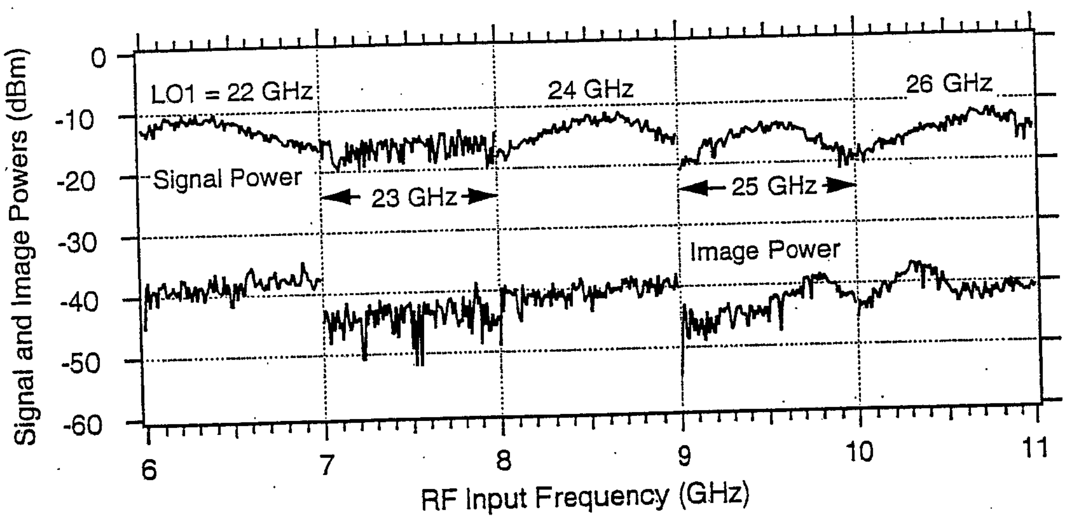


Figure 6